University of Southampton

Faculty of Engineering and Physical Science
School of Electronics and Computer Science

Impact of Induced Stress on Individual Performance, Team Coordination, and Human-AI Collaboration

by

Lokesh Singh

Supervisor: Prof. Sarvapali Ramchurn

ORCiD: 0000-0002-3938-1416

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Abstract

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A range of applications involves human teams working under pressure on complicated tasks that require well-coordinated action planning to function effectively. This includes, for example, disaster response, where groups of emergency responders work together to locate casualties; air traffic control, where controllers need to predict potential accidents; and emergency operating rooms, where multiple clinicians operate on patients. Human performance is known to be affected by the level of stress that individuals are subjected to during the performance of tasks. The team members must have clear communication, mutual trust, and a shared understanding of the task to work efficiently and effectively under stress. It also needs to be clarified how stress affects individuals working in a team or the team as a whole. This thesis aims to uncover critical interactional and task-related elements that affect individual and team performance under stress. Specifically, we focus on stress induced by time pressure, performance pressure, and audio distraction and study how incorporating verbal and nonverbal cues impacts team coordination and performance. We conducted a series of experiments using online and in-person tasks.

Firstly, a task was designed to monitor individual performance under time pressure and auditory distraction. The experiment was conducted remotely, measuring the performance of 32 participants. Our findings indicate that time pressure-induced stress positively impacts individual performance. Second, we divided participants into low, medium, and high-performing groups based on their overall performance in individual tasks into eight teams. Again, the experiment was conducted remotely using Google Sheets and measured the performance of all eight teams. The study found that time-pressure-induced stress negatively affects team performance. Additionally, we analyzed the coordination strategies used by high- and low-performing teams, showing that high-performing teams use more implicit coordination and have a high anticipation ratio. Third, we designed another experiment to understand the influence of automated agents on individual performance. This in-person experiment involved 32 participants competing against

automated agents. The analysis of the results revealed that the automated agents' performance significantly influenced participants' performance. Participants' overall performance was slower when competing with slow agents, whereas competition with fast agents improved performance.

Overall, our experiments provide insights into how stress and automated agents affect individual performance, team performance, and team coordination.

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Declaration of Authorship

I declare that this thesis and the work presented in it is my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published as: Lokesh Singh, Sarvapali Ramchurn, Obaid Malik, and Jediah R Clark. Understanding the impact of induced stress on team coordination strategy in multi-user environments. 2022
   Lokesh Singh and Gopal Ramchurn. The effect of automated agents on individual performance under induced stress. 2023

Signed:.. Date:..................

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Last but by no means least, my enduring gratitude goes out to my family: my parents, my brother, and my girlfriend. Your steadfast love, unwavering faith, and continual encouragement have been my pillars of strength. This accomplishment is not just mine but a reflection of the collective efforts and sacrifices you have all made on my behalf.

Acronyms

EEG	ELECTROENCEPHALOGRAM
ST	SKIN TEMPERATURE
EEG	ELECTROCARDIOGRAM
EMG	ELECTROMYOGRAM
GSR	GALVANIC SKIN RESPONSE
RSP	RESPIRATION
SMO	SEQUENTIAL MINIMAL OPTIMIZATION
HF	HUMAN FACTORS
HCI	HUMAN-COMPUTER INTERACTION
AI	ARTIFICIAL INTELLIGENCE
ANS	AUTONOMOUS NERVOUS SYSTEM
SNS	SYMPATHETIC NERVOUS SYSTEM
BP	BLOOD PRESSURE
PD	PUPIL DIAMETER
FMRI	FUNCTIONAL MAGNETIC RESPONSE IMAGING
ERP	EVENT RELATED POTENTIAL
HR	HEART RATE
HRV	HEART RATE VARIABILITY
LF	LOW FREQUENCY
HF	HIGH FREQUENCY
LDA	LINEAR DISCRIMINANT ANALYSIS
SCL	SKIN CONDUCTANCE LEVEL
PPG	PHOTOPLETHYSMOGRAPHY
SD	STANDARD DEVIATION
PSS	PERCEIVED STRESS SCALE
IBI	INTER-BEAT INTERVAL

Chapter 1

Introduction

In this chapter, we provide a concise overview of the background, motivation, problem description, research aim, methodology, research contribution and thesis structure.

1.1 Background and Context

Stress has become a pervasive issue affecting many individuals globally, detrimental to personal health and organisational finances. Stress ranks the second most common work-related health challenge in Europe (Alberdi et al., 2016b). In the United Kingdom, work-related stress is a significant issue, as evidenced by the Health and Safety Executive's (HSE) report that 595,000 individuals reported experiencing stress in 2017-2018 at a level that they believed was contributing to depression, which accounts for 40% of all work-related illnesses. Additionally, each person affected by stress loses an average of 23.9 workdays (Health and Executive). In 1956, Seyle proposed that stress is the body's non-specific response to work demands (Selye, 1956). Work-related stress can intensify during critical situations that require decision-making. In her 1997 book, Rosalind Picard coined the term "affective computing" (Picard, 1999). This term encompasses investigating and advancing systems and devices that can identify, comprehend, process, and replicate human emotions. This interdisciplinary field combines computer science, signal processing, psychology, and cognitive science. Picard explained why computers must express and recognise affect and emotion, which could enhance the human-computer interaction standard and advance stress detection methods. In 2003 (Picard, 2003), she identified the significant challenges associated with affective computing, including identifying stress, emotion, and mental state.

Human stress monitoring approaches mentioned in the literature involve measuring and evaluating individuals' physiological, cognitive, and behavioural responses to stressors. The process entails collecting and analysing data from various sources, such as sensors, surveys, and physiological measurements, to identify patterns and changes in an individual's stress response. Physiological measurements are crucial in monitoring changes in the body's responses to stress, including heart rate variability (HRV), blood pressure (BP), electroencephalogram (EEG), respiration rate (RSP), skin temperature (ST), and galvanic skin response (GSR). These measures can be collected non-invasively using wearable sensors or other devices (Collet et al., 1997) (de Santos Sierra et al., 2011). Cognitive assessments are used to evaluate how individuals perceive, process, and respond to stress, including self-reported measures of stress, cognitive testing, and neuropsychological assessments (Mahlke et al., 2006). Behavioural assessments involve observing how individuals respond to stressors, including facial expressions, body language, and vocal cues. Human stress levels are increasingly being monitored using methods based on machine learning (Collet et al., 1997). Within these methodologies, extensive datasets encompassing physiological, cognitive, and behavioural reactions to stress serve as the foundation for training algorithms, enabling them to discern patterns and forecast forthcoming responses. When an individual undergoes stress, they may grapple with a spectrum of emotions, including but not limited to anxiety, fear, anger, sadness, or frustration. These emotions can exacerbate each other, resulting in physical symptoms and physiological changes. Therefore, it is crucial to classify these emotions and understand their association with stress. Emotion recognition through machine learning models has found applications in various domains, for instance, Monitoring Mental Health (Guo et al., 2013), Air Traffic Control (Rodrigues et al., 2018), Social Safety (Verschuere et al., 2006) and Safe Driving (De Nadai et al., 2016). These approaches have the potential to provide real-time monitoring of an individual's stress level. They can be used in various settings, including healthcare, workplace, and personal stress management.

Researchers have utilised various approaches to investigate stress issues associated with human-computer interaction, such as laboratory studies, cross-sectional surveys, longitudinal case studies, and intervention studies. However, much of the research has focused on user state modelling for a single subject regarding process control, such as on naval ships (Neerincx et al., 2009). Typically, structured tasks are used in the laboratory setting to assess the impact of varying levels of mental workload on a single subject. Nevertheless, these tasks are often simplistic and do not reflect the complexities of real-life scenarios involving coordination-based critical decision-making tasks with multiple individuals. Research on modelling the states of multiple users is limited. Thus, developing a technology capable of evaluating multiple users' emotional states and cognitive load in critical decision-making situations is crucial. This study aims to investigate how such technology can be developed. It is crucial to detect stress early, especially in multi-user collaborative environments. Air Traffic Control and Disaster Management are prime environments where multiple people work together on the same tasks. It is necessary for users working together in teams with high precision and coordination to remain calm and composed while making critical decisions during highly stressful situations. The fundamental goal of this report is to analyse individual stress levels and evaluate the impact of stress on individual performance. The secondary objective is to understand the impact of induced stress and performance pressure on teams in collaborative environments. The third objective is to investigate how individual performance is affected by fellow participants under a reward system. Lastly, this report aims to develop an emotion/mental state recognition model to detect stress and its influence on decision-making.

1.2 Motivation and Problem Description

Aviation safety has long been paramount, with continuous efforts to enhance safety measures and prevent catastrophic incidents. One of the most compelling motivations for researching and understanding the dynamics of teamwork, coordination, and communication in high-pressure environments like aviation is the stark contrast between incidents that showcase effective teamwork and those marred by breakdowns in collaboration.

The first incident, United Airlines Flight 232 in July 1989, serves as a powerful illustration of the positive impact of teamwork under extreme circumstances. Despite the tragic loss of 111 lives, this incident highlighted that effective team coordination, interaction, and communication can make a critical difference in averting even greater disasters. The subsequent analysis, particularly the insights gleaned from the cockpit transcripts (Predmore, 1991), underscored the pivotal role played by teamwork in the crew's response to the emergency. Conversely, the second incident in December 1978 near Portland, Oregon, is a stark reminder of the consequences of poor teamwork and coordination. The National Transportation Safety Board (NTSB) report in 1979 attributed the accident primarily to a breakdown in teamwork, citing the flight crew's inability to effectively manage the aircraft's fuel supply and the lack of precise coordination with the airline maintenance team. This incident exemplifies the severe repercussions that can arise when team dynamics falter in critical situations. These two contrasting incidents offer a compelling motivation for our research. They demonstrate that the ability to foster effective teamwork and communication among aviation professionals is not just a theoretical concern but a matter of life and death. By studying these incidents, we can gain invaluable insights into the factors contributing to successful collaboration and, conversely, the factors leading to its breakdown. Our research aims to delve deeper into the nuances of teamwork and communication in high-stress environments to enhance aviation safety and prevent tragic accidents like those described above. In a review of crew performance in aviation, Foushee (Foushee, 1982) noted that most accidents are related to crew or team coordination breakdowns. Effective crew performance in aviation relies heavily on crew coordination and communication. Crew resource management training can effectively improve crew performance and enhance teamwork. However, fatigue, stress, and workload can impact crew performance and decision-making. Additionally, depending on its design and usage, automation can positively and negatively impact crew performance. The paper (Foushee, 1982) highlights the significant contribution of human error to accidents in aviation and emphasises the need to identify and address underlying factors to improve safety.

In summary, the importance of effective crew performance and teamwork in aviation is emphasised, and ongoing training and research are necessary to improve safety in the field. Why do stress or emergencies make team coordination more difficult? Research on individual stress reactions suggests that under stress, attention shifts from a wider to a narrower state, causing individuals to miss or ignore relevant information in their surroundings potentially Easterbrook (1959). This can have critical implications for effective team coordination, resulting in communication breakdowns and reduced cooperation between team members. Additionally, stress affecting one team member's behaviour can impact the entire team's performance. Hence, teams need to recognise the potential impact of individual stress on team coordination and behaviour, have strategies to manage stress, and maintain effective communication and cooperation. In highly coordinated teams, failure by a single team member can jeopardise the entire operation. Therefore, it is important to develop systems that identify and manage stress levels for each team member. While considerable work has been done on detecting stress levels in individuals (Driskell and Salas, 1991), there is a lack of research on detecting stress in multi-user environments. As stress levels in these environments are directly related to task and team coordination, it is necessary to study subjects involved in these activities as a group to identify stress and assess its impact on individual and team performance.

The multi-user collaborative environment enables us to understand the threshold levels associated with stress and baseline stress levels when users are involved in a task with similar goals and high levels of coordination. Stressful situations will increase the stress level of each individual. However, the dynamic baseline for detecting stress in these situations will vary for different tasks. The multi-user environment specifically enables us to compute the baseline stress level. This baseline stress level further allows us to detect individuals whose stress levels deviate significantly from this baseline. By detecting anomalies in these situations, it is possible to optimise the performance of teams involved in critical operations such as Air traffic control, disaster response, and emergency operating rooms. While it is intuitive to understand that some situations will induce a higher stress level in most individuals, detecting those disproportionately affected by such events or tasks is necessary. The main objective of this research is to simulate a stressful environment and detect the baseline stress level and the threshold limit beyond which an individual can be classified as an anomaly with exceptional stress levels.

1.3 Research Questions and Objectives

This section outlines the central research questions guiding this study on the effects of induced stress and performance pressure on individual and team performance and the impact of automated agents on individual performance. Clear articulation of these questions is essential as it forms the foundation for subsequent discussions and analyses within this thesis.

1.3.1 Overall Research Questions

1. **RQ1:** What is the relationship between varying levels of induced stress and individual performance? What factors significantly influence individual performance under stress?
2. **RQ2:** How does an individual's performance under stress impact team coordination and collaboration in high-pressure situations? What elements contribute to successful teamwork in these challenging circumstances?
3. **RQ3:** To what extent do automated agents and team members influence an individual's performance under induced stress? What strategies can optimize support in high-pressure situations involving both human and automated agents?

1.3.2 Objectives Corresponding to Research Questions

1. **Objective 1:** Conduct an in-depth analysis to explore the link between different levels of induced stress and individual performance. Identify and examine the factors that exert influence on individual performance under stress.
2. **Objective 2:** Investigate the impact of an individual's performance under induced stress on team coordination and collaboration in high-pressure situations. Identify crucial elements contributing to successful teamwork under such circumstances.
3. **Objective 3:**: Examine the influence of automated agents on an individual's performance under stress. It seeks to uncover practical approaches to assist individuals in demanding situations.

Overall, this study investigates the impact of induced stress, performance pressure and automated agents on individual and team performance. Addressing the specified research questions. Two user studies were conducted to investigate these inquiries: Study 1 focuses on RQ1 and RQ2, while Study 2 addresses RQ3. The results of this research offer substantial promise for organizations and teams functioning in high-pressure environments. The insights obtained have the potential to guide the creation of innovative training and support initiatives, ultimately improving the performance of individuals and teams in challenging situations.

1.4 Methodology

This section provides an abstract overview of the methodology employed in this research, addressing key components such as research design, participants, and data collection across both online and in-person experimental scenarios.

1. **Research Design**

   The research design encompasses three experimental studies; due to the evolving COVID-19 Situation, two studies were conducted online, while one was an in-person lab-based study. The first study was designed to ensure seamless synchronization between participants in different locations while participating in the remote experiment. The second study was in person in a lab-based environment for a more controlled setting. The Perceived Stress Scale (PSS) test measured the participants' stress levels. Additionally, the NASA Task Load Index (TLX) was used to investigate the participants' psychological stress responses. Questionnaires were employed to gather participant feedback and assess their responses during the task. Overall, these studies enabled the collection of relevant data to investigate the effects of induced stress, performance pressure and automated agents on individual and team performance under induced stress

2. **Participants**

   A total of 64 participants were recruited, comprising individuals with diverse professional backgrounds and students. Participants engaged in various experimental setups, including online scenarios with 32 participants and an in-person lab-based experiment with an additional 32 participants. Adhered to university standards and received approval from the relevant ethics committees.

3. **Data Collection**

   Data collection involved a combination of quantitative and qualitative measures. For the online experiments, data included player demographics, perceived stress scale, NASA-TLX ratings, questionnaires, and video-recorded task performance. The in-person experiment expanded data collection to include facial expression recordings. Across all sessions, the emphasis was on assessing immediate stress levels, team coordination, individual performance and team performance.

4. **Compensation and Ethical Considerations**

   Participants received monetary compensation, adhering to university standards and ethical approval. This compensation aimed to acknowledge participants' time and effort.

5. **A. Remote Experiment**

   The remote experiment, conducted over two days with 16 sessions, focused on understanding individual and team performance under induced stress and team coordination under performance pressure. Data collection involved participant engagement through Microsoft Teams, OBS task recording, and assessments such as NASA-TLX and questionnaires.

6. **B. In-person Experiment**

   The in-person experiment spanned seven days and explored individual performance in interactions with automated agents. Data collection involved individual performance concerning automated agents, facial expressions, NASA-TLX and questionnaires.

1.5 Research Contribution

In this section, we present the overarching contributions of our research, concentrating on the development of stress induction models aimed at scrutinizing individual and team performance under induced stress, along with individual capabilities concerning automated agents.

Our study significantly contributes to Human-Computer Interaction (HCI) and Human Factors (HF) by advancing understanding in key research domains. Firstly, in the domain of individual performance under stress, we innovatively developed two stress induction models tailored for online and controlled laboratory settings. Leveraging Google Sheets, participants engaged in tasks amidst auditory distractions and simultaneous time pressures, allowing us to discern nuanced stress responses. Moving to team performance and coordination, we introduced a multi-user stress induction model for remote collaboration. By actively monitoring team responses, we explored variations in stress levels during coordinated teamwork, emphasizing the reciprocal impact of individual performance on overall team success. Task designs were implemented via Google Sheets, and incentives and synchronized stress inductions were incorporated for enhanced participant engagement. Our research designed an experimental task to assess performance under time pressure in individual performance with automated agents. Implemented in an in-person setting, the task fostered a competitive atmosphere with visible automated agent performances. To heighten performance pressure, we introduced a potential monetary reward system, encouraging participants to surpass the capabilities of automated agents.

These cumulative contributions significantly advance the comprehension of stress effects on individual and team performance and capabilities concerning automated agents within the broader research domains of HCI and HF.

1.6 Structure of The Thesis

This report is organized as follows:

Chapter 1: explains the background, motivation, problem description, research questions, objectives, methodology, and research contribution. It demonstrates theoretical and practical motivation. It also outlines the study goals and outlines the rest of the content.

Chapter 2: presents a review of various state-of-the-art approaches to stress and performance and also provides insight into some of the backgrounds related to stress measurements, Stress Induction tests, Individual performance, Team Performance, team coordination, stress-workload relationship and automated agents. This chapter also provides insight into the various physiological signals. Ultimately, we briefly explain the impact of induced stress and automated agents on performance.

Chapter 3: present study design for individual and team performance, which includes motivation, individual performance measurement task, team performance and coordination measurement task, perceived stress scale, questionnaire, and NASA-TLX. It also includes the results from individual and team performance task design, which includes the Perceived stress scale, NASA-TLX analysis, questionnaire analysis, Individual expertise, team performance, team coordination results, validation of previous studies and summary.

Chapter 4: present study design for understanding human performance with automated agents, which includes individual performance measurement with automated agents, perceived stress scale, questionnaire, and NASA-TLX. It also explains the results from individual performance with automated agents' task design, which includes the perceived stress scale, NASA-TLX analysis, questionnaire analysis, performance with automated agents' results, validation of previous studies, and summary.

Chapter 5: explains the practical implications and applicability of our research findings in real-world contexts, detailing the utility of the designed tasks and the significance of the results obtained

Chapter 6: This chapter highlights the limitations, discusses key points, suggests areas for future research, and concludes with some final remarks.

1.7 Publications

1. **Singh, L.**, Ramchurn, S., Malik, O., Clark. J., (2022) 'Understanding the impact of induced stress on team coordination strategy in multi-user environments. **Applied Human Factor and Ergonomics**. (Published)
   This paper, which has won the **Best Paper Award**, tightens its content from both Chapter 3 and Chapter 4.

2. **Singh, L.** and Ramchurn, S. (2023) 'Impact of Automated agents on individual performance under induced stress, **Applied Human Factor and Ergonomics.** (Accepted)
   This paper converges its content from both Chapter 5 and Chapter 6

3. **Singh, L.** and Ramchurn, S. (2023) 'An attempt to explore how time pressure and auditory distraction affect individual and team decision-making'. **ACM Transaction on Computer-Human Interaction.** (Submitted)
   This paper represents an extended version of a conference paper developed using content from Chapter 3 and Chapter 4.

Chapter 2

Literature Review

In Chapter 1, we established the significance of investigating individual performance and teamwork in stressful situations. In this present chapter, we provide a concise overview of several crucial aspects. This chapter is organized as follows: Section 2.1 investigates stress and its effects. In Section 2.2, we explore the measurement of stress in more depth. Section 2.3 explores the relationship between stress and workload. Section 2.4 focuses on understanding individual and team performance within the context of stress. Section 2.5 explores cognitive performance under stress conditions. Section 2.6 explains the concept of implicit and explicit coordination concerning team decision-making under stress. Section 2.7 is dedicated to understanding the role of automated agents concerning performance. Finally, Section 2.8 summarises the chapter's key points and insights.

2.1 Stress

Stress is a common phenomenon that has an impact on people in a variety of contexts, including educational, employment, and personal ones. Working under stress is a shared experience experienced in many fields, such as medical emergencies, air traffic control, natural disaster management, sports, and business. It is essential to comprehend how stress affects human performance because it dramatically impacts people's well-being and ability to succeed. The term stress, first used in the 14th century in a non-technical sense, refers to hardship, straits, or affliction (Lumsden, 1981). In the 17th century, (Lawrence E. Hinkle, 1974) proposed a study of stress. The analysis was based on three fundamental concepts: load, stress and strain. Load refers to external forces, stress is a structural area, and strain is structural deformation. This work greatly influenced the models of emotional stress in the 20th century. The social, physiological and psychological factors act as an external force that boosts or reduces stress depending on the circumstances. In 1996, the World Health Organization published studies regarding the Global Burden of Disease, which indicated that depression, stress and anxiety disorders are persistent, second only to heart diseases.

Humans can experience various types of stress, which include acute stress, eustress, chronic stress, environmental stress, psychological or emotional stress, social stress, occupational stress, and physiological stress. Although several types of stress often overlap and individuals may experience several at once, not all stress types are harmful or undesirable. Acute stress is a brief form of stress that can either have a positive or distressing impact. (Shields et al., 2019) imply that mild acute stress decreases reaction time during the implementation of a task requiring selective attention. Mild stress improved the execution of motor actions, contributing to decreased response time (Increased speed). Stress is highly subjective; distress for one is eustress for another and nonevent for the third. The relationship between a stressor and a task is essential in determining whether individual and team performance will be enhanced or impaired (LeBlanc, 2009). Chronic stress is long-term stress that persists over a more extended period. Long-term or chronic stressors exhibit a stronger correlation with the manifestation of depressive symptoms compared to short-term or acute stressors (Marin et al., 2011). Environmental stress refers to the negative impact that various environmental factors, such as noise, pollution, and temperature, can have on humans (Lazarus and Cohen, 1977). Social stress emerges from interpersonal interaction and relationships. It can occur due to conflicts, social pressure, peer pressure, or feeling judged or excluded (Aneshensel, 1992). At the same time, Occupational stress is related to the work environment, such as high workload, time pressure, job insecurity, lack of control, conflicts with colleagues or dissatisfaction with work (Motowidlo et al., 1986). On the other hand, physical stress occurs when the body experiences physical strain or disruption, such as illness, injury, lack of sleep, poor nutrition, or excessive physical exertion (Hepler, 2015). It is crucial to remember that various stress types frequently overlap or interact, and people may feel several stress types simultaneously. Since the effects of stress can differ from person to person, it is essential to learn efficient coping mechanisms and seek assistance when needed to control stress levels and preserve general well-being.

2.2 Stress Measurements

Symptoms of stress can be measured and observed in many ways. Stress is ignited by the Sympathetic Nervous System (SNS), resulting in psychological, physiological and behavioural changes (Kyrou and Tsigos, 2009). One psychological method of measuring stress is self-reported questionnaires or consulting a psychologist (Alberdi et al., 2016a). This psychological method does not include automatic stress detection topics. Another way to detect stress is by evaluating physiological signals and behavioural changes (Zimmermann et al., 2003). Physiological signals include

Electroencephalogram (EEG), Electrocardiogram (ECG), Electrodermal Activity (EDA), Galvanic skin response (GSR), Blood pressure (BP), Electromyogram (EMG), Skin temperature (ST), Respiration, Pupil diameter (PD), Eye Gaze, Eye Blinking and Functional Magnetic Resonance Imaging (fMRI) are known as biomedical signals. The recommended position of biosensors is shown in Figure 2.1.

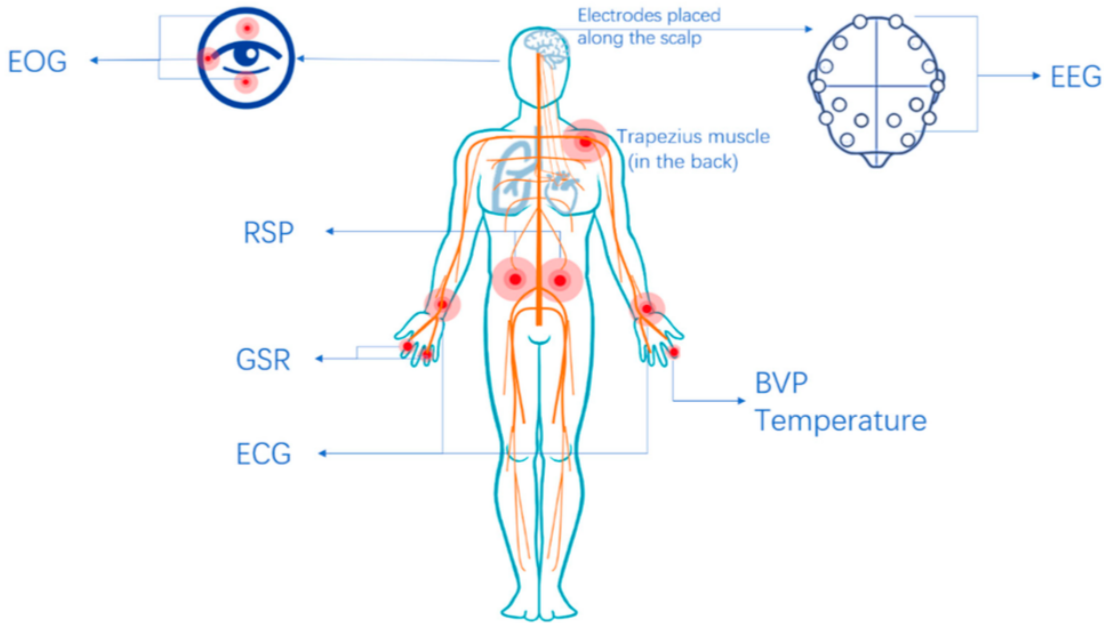

FIGURE 2.1: Strategic placement of biomedical sensors for physiological signal monitoring.

The study of biomedical signals is vital to understanding human behaviour. These could help us understand the cause of stress, which could help us develop a stress detection model. Figure 2.2 shows a few examples of physiological signals. Stress affects people's behaviour, and these behavioural changes can be monitored without intrusive procedures and the need for extra equipment. These sensors can be attached to different body parts for data collection, as shown in Figure 2.1. Behavioural actions include posture, facial expressions, voice, mobile phone use, and walking style. These behavioural action data can be collocated using sensors. Stress detection is usually done by calculating and evaluating different human body parameters or electrical pulses.

- Brain Activity $\longrightarrow$ Electroencephalogram (EEG)
- Heart Activity $\longrightarrow$ Electrocardiogram (ECG)
- Skin Response $\longrightarrow$
  Galvanic Skin Response (GSR) and Electrodermal Activity (EDA)
- Blood Activity $\longrightarrow$ Photoplethysmography (PPG)

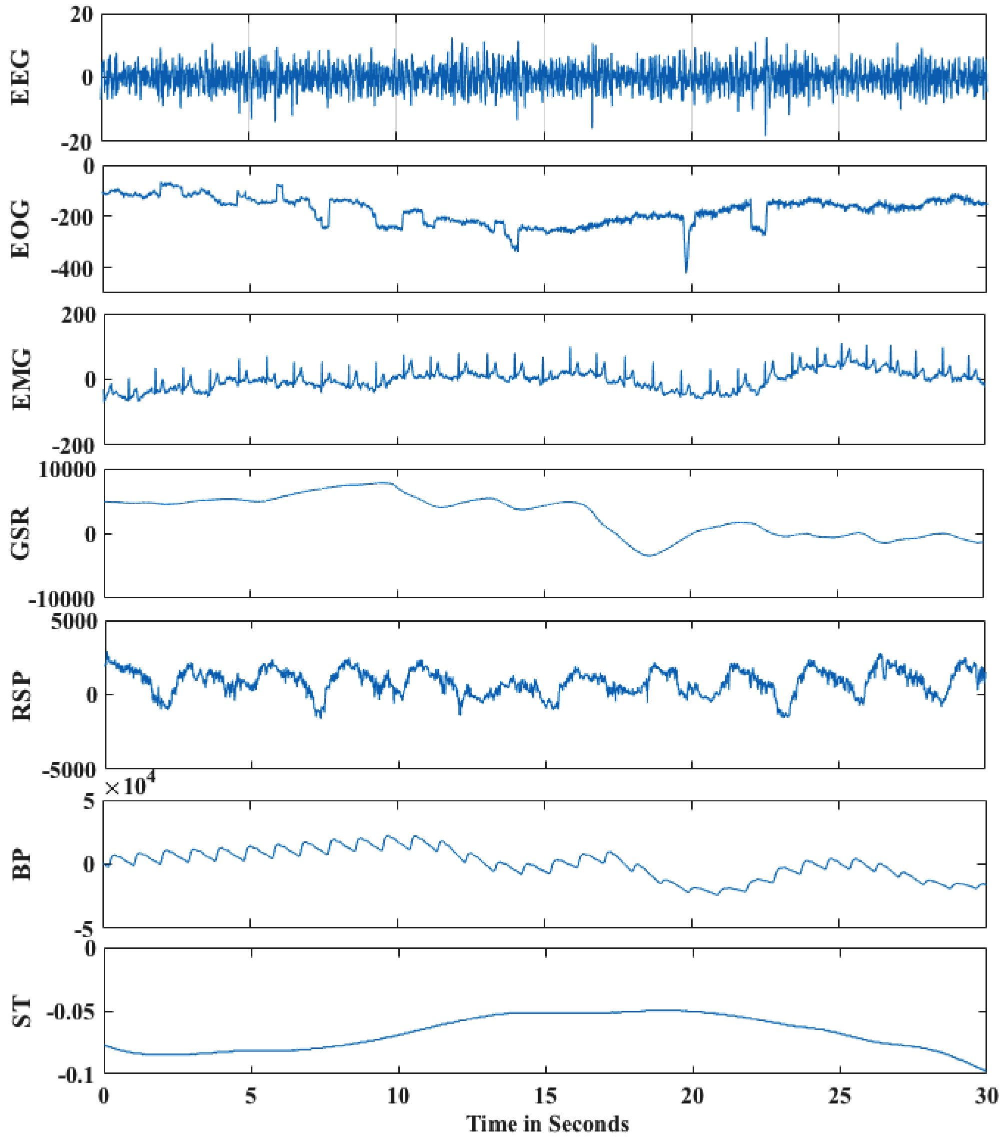

FIGURE 2.2: Key physiological sample signals extracted for stress detection from the DEAP dataset (30-second duration) (Koelstra et al., 2011).

- Muscle Activity ⟶ Electromyography (EMG)
- Respiratory Response ⟶ Piezoelectricity or Electromagnetic Generation
- Facial Expression ⟶ Automated Facial Expression Analysis (AFEA)
- Eye Activity ⟶ Infrared (IR) Eye Tracking
- Body Gesture ⟶ Automated Gesture Analysis (Leveraging AFEA)

2.2.1 Stress Induction Test for Inducing Stress

To investigate stress, it is often necessary to induce stress in subjects through specific activities conducted in laboratory settings. This section briefly overviews the most common laboratory tests used to induce stress.

2.2.2 Trier Social Stress Test (TSST)

The TSST is the most common stress induction test. This test takes 15 minutes to complete. It consists of three stages and is divided into three steps(Kirschbaum et al., 1993). Saliva and blood samples are extracted for the test to record the heart rate results. The evaluation is performed in a room with a video camera, microphone and three judges. Judges are trained to manage their gestures as neutral. The subject is asked to prepare a five-minute presentation in the first phase. The presentation is prepared on paper and a pen. The document is suddenly removed from the subject after the first step. The subject is then asked to submit the material in the second phase. The judges listened to the presentation without any interference. If the subject completes the presentation within five minutes, he or she should proceed. The final stage is a mental arithmetic task in front of the judges. The subject is asked to deduct 13 steps from 1022. If the subject makes an error, he/she is asked to start from the beginning. The recovery period starts after the end of the third stage. Samples and signals are obtained and stored until the end of the recovery period. The subject is informed about the intent of the test at the end of the test.

2.2.3 Montreal Imaging Stress Test (MIST)

The Montreal Imaging Stress Task (MIST) is a variation of the trier test. This task requires using the computer program to introduce computerised mental arithmetic challenges and to determine social threats. The investigator conducts three stages (rest, control and experimental) to identify the effects of stress and mental calculation. (Dedovic et al., 2005). The subject is observed in these stages via functional magnetic resonance imaging (fMRI). In this step, subjects will not be asked to perform any tasks. The subjects will be shown a series of mental arithmetic tasks. In this phase, subjects respond to tasks using the given computer program. In the last phase, the complexity of the task is increased, and the time limit is reduced. The purpose is to increase the task's difficulty in determining the individual's mental abilities. At the end of each task, the average participant performance and expected completion time of the subject increase the participant's stress.

2.2.4 Stroop Color-Word Interface Test (SCWT)

One of the most common and oldest stress induction tests is the Stroop Color-Word Test (Stroop, 1935). Multiple test variations were created by changing the number of subtasks, type and number of stimuli, and times for the task or scoring procedures (Lezak et al., 2004). In the regular version, the test subject is asked to read the name of the colour word. This activity is regarded as word reading. The second activity is to label the ink colour. The last activity is to call the colour of the word on the display. An SCWT sample example is shown in Figure 2.3.

FIGURE 2.3: Stroop color-word interface test setup for assessing cognitive processing speed and selective attention (Scarpina and Tagini, 2017).

2.2.5 Cold Pressor Test (CPT)

Another stress-induced test is the cold pressor test, which involves placing the participant's hand in an ice water tub (3°C) up to Elbow. The test procedure is as follows: The subject of the test is expected to put his or her hand in the cold water tube as long as he/she can. If they feel pain, they are told to express it. Participants were told that they could withdraw their hands if the pain became unbearable and were told when the 3 minutes had elapsed. It helps researchers to evaluate the threshold and tolerance. This stress-induced test is the most commonly performed model of the cold pressing task (Wood et al., 1984).

2.2.6 Sing-a-Song Stress Test (SSST)

A new stress induction method named SSST has been developed. In this test, neutral messages are displayed on the screen for one minute. After this neutral phase, participants are requested to sing aloud. While singing, participants have to remain still. It was observed that SSST induces mental stress in a fast, simple, regulated and effective way (Brouwer and Hogervorst, 2014). During the neutral phase and while singing, they tested the ECG and EDA signals, which showed that the two stages are significantly different, correlating stress level and singing.

2.2.7 International Affective Picture System Test (IAPS)

The IAPS was created by the National Institute of Mental Health Center for Emotion and Attention in collaboration with the University of Florida (Lang, 2005). It contains photographs from simple household items to graphic photos that excite viewers (mutilated bodies, erotic and violent scenes). This method is commonly used in literature for stress induction by showing a collection of IAPS photographs.

2.3 Stress and Workload Relationship

The relationship between stress and workload has been a focal point in organizational psychology and occupational research for decades. According to a seminal study by (Karasek Jr, 1979), the Job Demand-Control model Suggests that high job demands coupled with low control can lead to increased job strain, which encompasses elements of stress and workload (Karasek Jr, 1979). Building on this foundation, subsequent research has expanded our understanding, revealing the multifaceted nature of this relationship. One significant aspect that emerges from the literature is the detrimental impact of excessive workload on individual well-being and performance. (Carayon, 1993) explored the concept of job stress and its implications, emphasizing that prolonged exposure to high workloads without adequate recovery periods can lead to adverse health outcomes, including cardiovascular diseases and mental health disorders. Furthermore, studies such as Siegrist's on the Effort-Reward Imbalance model highlight how discrepancies between effort expended and rewards received in the workplace can contribute to heightened stress levels, further exacerbating workload perceptions (Siegrist, 1996).

Conversely, the relationship also reveals a cyclical nature wherein increased stress levels can amplify perceptions of workload, creating a self-perpetuating strain cycle. Research by Lazarus and Folkman (Lazarus and Folkman, 1984) on the Transactional Model of Stress and Coping elucidates how individuals' cognitive appraisal of workload demands influences their stress responses, emphasizing the role of individual perceptions and coping mechanisms in modulating these effects. Moreover, recent empirical evidence underscores the importance of recovery processes, indicating that interventions that facilitate adequate recovery can mitigate the adverse effects of high workload and stress on performance and well-being (Sonnentag et al., 2017).

2.4 Individual and Team Performance Under Stress

Several theoretical frameworks may assist in understanding dynamics when researching the effects of induced stress on individual and team performance. According to Lazarus and Folkman's cognitive appraisal theory (Lazarus and Folkman, 1984), how people interpret and evaluate stressors significantly impacts how they react to stress and how well they function. It focuses on how people view and assess stressors, including their importance, controllability, and potential for good or bad, and how this affects how they think, feel, and behave. The Cognitive Appraisal Theory emphasises that emotions are influenced by people's subjective assessments and interpretations of events and by the objective qualities of those occurrences. This theory has significant implications for understanding and controlling emotions, stress, and coping. Another theory proposed by Posner and Petersen aims to clarify how cognitive processes control and regulate attention. The attentional control theory investigates how stress might influence a person's attentional functions, which may impact performance. Stress can affect the allocation of cognitive resources and attentional focus, either narrowing or broadening it. Alerting, Orienting and Executive control are three major components that interact and work together to regulate attention. It is easier to understand how stress affects attentional control and how it can improve or worsen performance using this framework, (Posner and Petersen, 1990). The resource allocation theory is another theory that asserts that each person has a limited quantity of cognitive resources at their disposal at any one time. These resources are distributed among various cognitive processes; the distribution is subject to change based on the needs and priorities of the tasks at hand. Under induced stress, people may develop resource exhaustion, which degrades performance (Liefner, 2003). This framework strongly emphasises resource management and potential trade-offs when deciding how much time and money to devote to stress management and how well a task will be completed. According to social facilitation theory, a person's performance may be influenced by the presence of others. The presence of colleagues or an audience might affect a person's performance under the influence of induced stress in a social setting. This concept investigates how social elements and induced stress interact to improve or worsen individual and team performance (Zajonc, 1965). According to the interactional stress theory, induced stress interacts with personal factors like personality traits, coping mechanisms, and social support to affect performance outcomes. It recognises that everyone reacts to stress differently depending on their specific traits and resources and that these things might regulate the effect of induced stress on performance (Endler and Magnusson, 1976).

2.5 Cognitive Performance Under Stress

Stress, cognitive performance, and emotional well-being are interconnected aspects of human experience. Understanding their relationship is essential for comprehending how stress can impact cognitive functioning and emotional states. Stress affects cognitive performance in many ways, and a combination of stress and memory function under study plays a vital role. The common factor relevant to the effect of stress on cognition includes intensity or magnitude. It could be triggered by a task, external factor or specific cognitive operation (Sandi, 2013). When a person experiences stress, their body's stress repose is activated. It releases hormones like cortisol, which can interfere with the prefrontal cortex, which is essential for attention and working memory and can affect the overall cognitive and brain activities. Specific distractions, including performance, time pressure, complex tasks, competitive environments and auditory distractions, can cause stress. Focusing attention on specific tasks is insufficient to prevent distractor interference. It takes complete focus on the work to actively balance the distractor and the target (Lavie, 2005). Therefore, creating a task that encourages complete participation from the participant is crucial. Additionally, stress affects both short-term and long-term memory. It may make encoding and synthesising new information more complex, making it easier to retain and recall facts. Five categorising factors impact memory: the source of stress, stressor duration, stressor severity, stressor timing concerning memory phase, and learning type (Sandi and Pinelo-Nava, 2007).

2.6 Team Coordination

This study aims to find out how team members adapt their strategy in the coordination-based task and what team structure best contribute to the team performance under a wide range of stressful condition. A range of challenges emerges when defining a team and establishing what team performance and collaboration involve. There have been numerous definitions of teams in the literature (Serfaty et al., 1993). A team is a distinct group of two or more people engaging toward a common goal/mission, and each is assigned a defined role to perform (Fiore et al., 2010). To achieve goals, teams must coordinate, communicate, and adapt strategies to the demands of tasks and support team processes. The academic literature provides many approaches for team coordination. Traditionally, research has concentrated on planning and communication as the primary coordination mechanisms. This study will comprehensively review the primary studies on teamwork coordination from explicit to implicit. Table 2.1 shows the description of implicit and explicit coordination groups. This study will focus on defining and developing teams to improve performance. It is essential to identify the factors that can enhance team performance.

2.6.1 Explicit Coordination

Explicit coordination, as explained by (Espinosa et al., 2004), entails the intended adoption of various processes facilitating different team members to manage their multiple interdependencies. Building upon this, extended research has contributed to a subtle understanding of explicit coordination within teams. Espinosa laid the groundwork for explicit coordination, emphasizing its role in synchronizing diverse interdependencies. Further insights can be gleaned from the work of (Kraut and Streeter, 1995), which investigates the complexities of explicit coordination within virtual teams. Their findings highlight the crucial role of explicit coordination mechanisms, such as shared calendars and task lists, in mitigating the challenges posed by physical dispersion. (March and Simon, 2005) introduced the term "coordination based on planning," signifying a set of techniques and methods employed by teams to manage the most stable and predictable components of their procedures. Expanding on this, the seminal work of (Marks et al., 2000) offers a detailed analysis of team planning processes. Their research highlights the significance of strategic planning among team members.

Communication-based coordination, another part of explicit coordination, involves sharing information between team members through various tracks. This concept finds resonance in the research by (Faraj and Xiao, 2006), who explore communication patterns within distributed teams. Their study uncovers the variation of formal and informal communication modes, shedding light on their impact on team coordination and performance. Moreover, the work of (Hinds and Bailey, 2003) investigates the role of oral and written transactions in communication-based coordination. Their study in the context of global virtual teams provides valuable insights into the challenges associated with different communication modes and offers strategies for effective coordination. Explicit coordination is a many-sided construct encompassing planning and communication-based mechanisms. The studies above provide a comprehensive overview, offering valuable insights into explicit coordination within diverse team contexts.

2.6.2 Implicit Coordination

Implicit coordination refers to a team's ability to work collaboratively by anticipating the demands of the task and their teammates and then adjusting their behaviour accordingly, without the necessity for direct communication among team members (Espinosa et al., 2004) (MacMillan et al., 2004). The following behaviours are indicative

TABLE 2.1: Description of implicit and explicit coordination presented in the table (Xiao et al., 2007)

Coordination Type	Subgroup of Coordination Type	Definition	Examples
Explicit coordination		Commanding other teammates to perform actions; Prom ting or requesting information from other teammates	"Pick up block from column one"
Implicit coordination	Deliberative	Information related to next block in sequence	"There is a lot of red colours"
	Reactive	Status updates not pertaining to the next block in the sequence	"I am waiting for that block to be removed"

of implicit coordination: 1) providing relevant information, knowledge, or comments to other team members without prior request; 2) sharing the workload or proactively assisting a coworker; 3) keeping track of activity progress and teammate performance; and 4) modifying one's behaviour to the actions required by others (Wittenbaum et al., 1996). Routine actions are likely to have a higher implicit coordination load. The presence of unknown and changing situations throughout the action phase will push the team to adjust established plans, boosting explicit coordination. Implicit coordination refers to a team's ability to work collaboratively by anticipating the demands of the task and their teammates and then adjusting their behaviour accordingly, without requiring direct communication among team members (Espinosa et al., 2004). Building upon this foundational understanding, numerous studies have contributed to a subtle exploration of implicit coordination, shedding light on its multifaceted nature within team dynamics. Espinosa lays the groundwork for implicit coordination, emphasizing its role in synchronizing team actions through shared understanding. Expanding on this, the work of(Kozlowski and Bell, 2003) provides insights into the behavioural dynamics of implicit coordination, highlighting how team members intuitively adjust their actions to align with shared objectives, cultivating a sense of cohesion.

(MacMillan et al., 2004) work investigates communication patterns indicative of implicit coordination. This aligns with the research by (Malone and Crowston, 1994), who explore the role of non-verbal cues in distributed teams. Their findings underscore the importance of subtle, non-verbal communication in implicitly coordinating team efforts. (Wittenbaum et al., 2004) contribute significantly by identifying specific behaviours characteristic of implicit coordination. Their comprehensive categorization includes providing relevant information without request, proactively sharing the workload, monitoring activity progress, and adapting behaviour to the actions of others. Further insights into implicit coordination behaviours are provided by (Jehn and Mannix, 2001), who explore how team members naturally synchronize their actions to enhance overall performance. Routine actions, as suggested by (Klimoski and Mohammed, 1994), tend to impose a higher implicit coordination load. They argue that teams rely more on implicit coordination in familiar contexts, emphasizing routine actions that align with established norms. Moreover, the presence of unknown and changing situations encourages teams to adjust established plans, thereby boosting explicit coordination. This aligns with the research of (Mohammed and Dumville, 2001), who investigate how teams shift from implicit to explicit coordination in response to environmental uncertainties. Implicit coordination involves a complex interplay of behaviours, communication patterns, and adaptive strategies within teams. The studies referenced above collectively contribute to a comprehensive understanding of implicit coordination, offering valuable insights into its role in enhancing team performance.

2.6.3 Team Decision-making Under Stress

People make decisions according to the situation in the real world, often when stress is present (Burke et al., 2018). Stress has been associated with a broad spectrum of consequences, encompassing physiological responses, cognitive impacts, emotional responses, social conduct, and performance results (Driskell and Salas, 2013). Furthermore, stress has been shown to affect how people make decisions (Starcke and Brand, 2012). Some argue that stress impacts team decisions by affecting how team members gather, weigh, and exchange information (Burke et al., 2018). Many tasks, such as air traffic control, are associated with high-risk outcomes. As an individual's demands increase, they may begin to feel stressed. A tempting intuitive assumption is that increased stress will generally degrade team performance. The truth appears to be far more complicated. The literature on the impact of individual performance (Kaplan et al., 1993) indicated a few trends. Stress tends to increase performance quantity while decreasing quality, focus on more critical task features, and prompt more simplified, heuristic information processing. This trend has been replicated in (Brown and Miller, 2000). Brown (Brown and Miller, 2000) indicates that increasing time pressures lead to increased task focus within performance groups. Within certain limits, groups appear to be able to adapt to higher stress levels; however, if such stress becomes excessive, group performance will eventually be degraded (Adelman et al., 2003). Efforts have been made to interpret how performance groups allocate their limited resources and identify optimal group performance strategies for combating process losses caused by stressful working conditions. Kelly and her colleagues have continued previous research on the effects of a specific source of stress—time pressure on collective performance (Kelly, 1988). As a result, groups given lax initial time limits can be trained to work slowly and carefully on a creativity task so that when they are later required to work under stressful, stringent time pressures, they will work more slowly but with higher quality than groups trained under more stringent time pressures Kelly and Karau (1993). These studies show how group members attribute tasks. This is concerning, given the link between stress and performance.

2.6.4 The Effect of Stress In Team Coordination

Researchers have proposed a variety of relationships between stress and performance, including negative linear, positive linear, and inverted-U shaped relationships (Kavanagh, 2005). There is a difference between positive stress (eustress) and distress in the psychology of emotion. Eustress has been linked to goal-oriented behaviour (Selye, 1976). Several studies have shown numerous types of stress (Beehr et al., 2000). When stress has a favourable impact on an individual, it has been linked to positive outcomes (LePine et al., 2004). (Selye, 1956) suggested an inverted-U relationship between stress and performance, which is consistent with the definition of stress as an unspecific force acting on individuals. Since then, this type of relationship has been more broadly defined as a relationship between arousal and performance, in which there is an optimal level of arousal and over- or under-arousal reduces performance. It is possible to detect stress from physiological and physical responses. Using what is known about the team decision-making process and the effects of stress on performance, two tasks of team decision-making in a collaborative environment under stress have been developed. Inter inter-variability is another difficult challenge in stress monitoring. Stress causes physiological reactions, but the pattern of the reactions differs from person to person. (Sakri et al., 2018) discovered features accuracy varied greatly from one subject to another. Multi-user environments make decisions in a variety of contexts and environments. Unfortunately, many of these contexts involve everyday stressors, including time pressure, ambiguity, and personal issues.

2.7 Automated Agents

Understanding the impact of automated agents under stress is of paramount importance across various sectors and disciplines. In emergency response scenarios, the ability to make quick and correct decisions can be a subject of life and death. Here, automated agents have the potential to significantly influence outcomes by either augmenting decision-making processes or introducing complexities that impede timely responses (Lee and Mihailidis, 2005). Likewise, within healthcare settings, where professionals frequently operate under heightened stress levels, the integration of automated agents can offer invaluable support. However, it's crucial to acknowledge that these agents may also introduce cognitive load, distractions, or even errors, depending on their design, functionality, and deployment context.

To Investigate deeper into this intricate relationship, our research adopts rigorous experimental methodologies. By employing stress induction techniques and comprehensive performance-based assessments, we aim to elucidate the nuanced effects of stress on interactions involving automated agents. Through meticulous data analysis, encompassing pattern recognition, correlation assessments, and identification of potential moderating factors, this study endeavours to offer actionable insights. Ultimately, our findings aspire to guide the design, development, and deployment of automated agents across diverse contexts, fostering optimal effectiveness while mitigating potential adverse repercussions.

2.7.1 Impact of Automated Agents

The impact of stress on human performance has been extensively studied (Matthews et al., 2000). Stress is an inevitable part of modern life. The impact of automated agents in various domains has prompted a shift in the examination of stress's influence on human performance. Extensive research has investigated the impact of stress on cognitive abilities, decision-making, and memory, laying a foundation for understanding how automated agents may exacerbate or alleviate these effects. This literature review examines how induced stress affects human performance in various areas, including cognition, decision-making, memory, and motor skills. According to research, acute stress can improve or worsen cognitive function depending on its intensity, duration, and specific elements (Klein, 1996). According to some studies, moderate stress can enhance cognitive performance by increasing attention, focus, and the rate at which information is processed (Singh et al., 2022). However, persistent or high stress levels have consistently been linked to cognitive dysfunction, including a decline in working memory capacity, a loss of executive control, and a decline in decision-making skills (Cohen, 1980).

The introduction of automated agents introduces an additional layer to the relationship between stress and decision-making. Research indicates that stress can render individuals more risk-averse decision-makers in the presence of automated agents, prioritizing the avoidance of potential losses over the pursuit of gains. This effect, attributed to increased emotional arousal and a narrowed focus on immediate threats, poses challenges to long-term strategic decision-making. The interplay between stress, automated agents, and memory function is intricate. Acute stress, facilitated by automated agents, can both enhance and impair memory recall, depending on the emotional charge of the memories involved. While emotionally charged memories may benefit from stress-induced consolidation (Roozendaal et al., 2009), retrieving neutral or unemotional information may become more challenging. Persistent stress in the presence of automated agents consistently correlates with adverse memory effects, affecting encoding, consolidation, and retrieval processes (McGaugh et al., 1992). Crucially, the influence of stress on human performance outcomes in the context of automated agents is subject to individual differences and environmental factors. Further research is imperative to elucidate the underlying mechanisms and develop effective stress management techniques, particularly tailored to the unique challenges posed by the integration of automated agents into human-centric systems (Lazarus and Folkman, 1984; Schwabe et al., 2009).

2.7.2 Impact of Reward

Over the last few decades, In some areas, the organisation's work culture has shifted from individual to team-based (Poole et al., 2004). The question of how individual expertise and team performance are related to one another is vital in determining what makes teams effective. The strongest team member has higher expertise in numerous performance measures (Ericsson and Smith, 1991). Expert team members perform well on the task and sub-tasks assigned to them (Hackman and Lorsch, 1987). Top performers are vital contributors to high team performance. This assumption is supported by empirical research. An experimental study conducted by Bottger and Yetton (Baumann and Bonner, 2004) found that counting on the expert member was positively associated with team performance. High performers are expected to contribute more to team performance and to motivate other team members to perform well. The effect of rewards on individual performance is a widely studied topic in organisational psychology and behavioural economics (Sarin and Mahajan, 2001). Numerous studies have investigated how rewards influence motivation, task engagement, and overall performance. Here are some key findings from the literature: Previous studies show how rewards can improve people's performance under pressure. Rewards improve cognitive function, support goal-directed behaviour, and lessen stress's detrimental effects on cognitive and behavioural outcomes. Dopaminergic pathways and the brain's reward circuitry are involved in the underlying mechanisms (Baumeister, 1984). However, the effects of rewards on performance are modulated by individual differences, the nature of the task, and the stressor. Intrinsic motivation refers to engaging in an activity for its inherent enjoyment or satisfaction, while extrinsic motivation involves engaging in an activity to obtain external rewards (Eisenberger et al., 1999). Offering extrinsic rewards for tasks that individuals find inherently exciting or enjoyable can sometimes decrease their intrinsic motivation, as the focus shifts to external rewards rather than the inherent satisfaction of the task itself. Performance-contingent rewards are tied to achieving specific performance goals. These rewards have been found to enhance task performance, mainly when the goals are challenging but achievable (Harackiewicz and Manderlink, 1984). They provide individuals with clear objectives and a sense of accomplishment when they are attained, thereby increasing motivation and effort. While rewards can initially boost performance, their long-term impact may be limited. Once individuals become accustomed to receiving rewards, their motivation can depend on rewards rather than intrinsic factors. This dependency can lead to a decrease in performance when rewards are removed or reduced. The impact of rewards on performance can vary across individuals. Some people may be more motivated by extrinsic rewards, while others may be driven by intrinsic factors or a combination of both. It is essential to consider individual preferences and needs when designing reward systems to maximise effectiveness.

2.8 Summary

The literature review explores the intricate relationship between stress and performance, encompassing various aspects such as human stress measurements, stress induction tests, how individuals and teams perform under stress, and how cognitive abilities are affected in stressful situations. Moreover, the review delves into how stress impacts team coordination, covering explicit and implicit coordination and decision-making processes during high-pressure scenarios. A critical area of investigation in this literature review pertains to the influence of stress on team coordination and the role of automated agents in such circumstances. The review aims to shed light on how stress can either positively or negatively affect the efficiency of team coordination, and it also examines the contributions of automated agents in mitigating or exacerbating stress-related challenges.

Additionally, the literature review meticulously examines the influence of stress on individual performance, taking into account various aspects such as cognitive abilities, decision-making skills, and overall task execution. Furthermore, the analysis includes studying how reward systems impact individual performance under stress, providing valuable insights into how incentives may influence performance outcomes in demanding situations. Throughout the review, numerous studies are carefully examined to identify trends, gaps, and potential avenues for future research. By skillfully collating and synthesizing existing knowledge on stress and performance, the literature review aims to deepen our understanding of how stress affects human and team capabilities, offering valuable strategies to optimize performance in high-stress environments.

Chapter 3

Understanding the Impact of Induced Stress on Individual and Team Performance

In the previous chapter, we established that stress has a substantial impact on individual and team performance. We reviewed valuable insights and strategies for optimizing performance in high-pressure environments. In the current chapter, our focus turns to the study design and results concerning individual and team performance. This comprehensive exploration encompasses various factors, including the methodology employed, an overview of the study design, participant details, the hypotheses being tested, the design of the tasks used for measuring individual and team performance, and the background measures. Section 3.1 provides detailed information on experiments in a constrained environment. Section 3.2 offers an in-depth explanation of the methodology used in the experiment, which includes the protocol, overview, and participant information. In Section 3.3, we outline the research questions with hypotheses being investigated. Section 3.4 explains the study Design for individual and team performance tasks. In Section 3.5, building upon the groundwork of the study design, we present the results of the experiment. We carefully explore the research findings in this section and provide insights into the results of the Perceived Stress Scale measurements, unravelling the psychological impact of stress on participants. We elaborate on the findings related to individual performance measurement, analyzing individual responses under induced stress, also focusing on the outcomes of team performance measurement and unveiling the collaborative dynamics within teams working in induced stress circumstances. We explore the evolving coordination tactics observed within teams. This section also includes the questionnaire and NASA-TLX analyses. Section 3.6 briefly summarizes the key insights from this chapter.

3.1 Contextual Constraints

To investigate stress, subjects are required to carry out certain activities in constrained environments to induce stress. The term "constrained environments" represents the stress detection/analysis technique with constraints, such as stress detection while driving, stress detection while sleeping, stress detection in a lab, and so on. These constraints help streamline detection by excluding real-life situations that cause a stress-like response in the human body (e.g., physical exercise, eating, hot weather, etc.). Because of the simplifications, these methods can only be used in the environment for which they were designed. Research is often carried out concerning user state modelling on a single subject and for process control, for example, on naval ships (Neerincx et al., 2009). More research needs to be done on modelling multiple user states. It is, therefore, essential to develop a technology that can work on multiple subjects. Developing a method in constrained conditions, on the other hand, allows for a detailed analysis of the stress response. This experiment highlighted the importance of setting up a collaborative environment involving close user coordination. Due to the circumstances surrounding COVID-19, it was essential to ensure that the experiment could be carried out remotely. Novel multi-user tasks were designed to ensure seamless synchronisation between participants at different locations and replicate a collaborative situation. Two such tasks were designed: easy to access, run on computers, use a standard browser, allow for collaborative work, etc.

3.2 Method

This two-day experiment was conducted online to examine immediate stress levels, understand team coordination strategies, and assess the effects of time pressure and auditory distraction on individual and team performance. The flow diagram of the experimental protocol is shown in Figure 3.1. Microsoft Teams was used to connect the researcher and participants, and the OBS was used to record the task activity. There were 16 sessions in total, each lasting about an hour. Each participant received a task design overview, an introduction to the study, and an informed consent form. The overview includes a demo of the Google Sheets display and directions on how to complete the task and communicate using the interface. Following that, participants were given the Perceived Stress Scale form to assess their immediate stress level at the time of participation in the study, followed by a 5-minute training session. The first experiment was to quantify individual expertise, which NASA-TLX and a questionnaire followed. The second experiment was carried out to assess team performance and coordination tactics in a collaborative environment, which was also followed by a questionnaire and a NASA-TLX form.

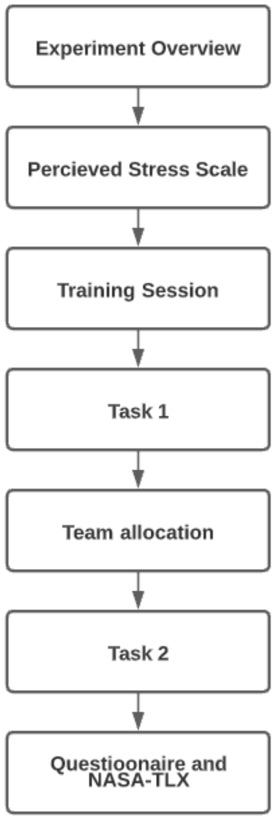

FIGURE 3.1: Illustrative flowchart depicting the sequential stages of the experiment, covering key components such as stress evaluation, training, task allocation, and post-task assessments.

3.2.1 Overview

This study investigated how individuals perform under different time constraints and auditory distractions. Participants participated individually in the first part of the study. Still, they are allowed to see other participants' performance so that we can study how participants' performance affects each other, followed by a second task in which they collaborate as a team to understand team performance and coordination tactics used by high- and low-performing teams. Concerning the task kinds, the tasks were similar but distinct from one another in terms of the specific task needs. Overall, the first task measured individual performance, whereas the second task measured team performance.

3.2.2 Participants

The participants consisted of 32 people (14 females and 18 males; mean age =27.5 years, SD = 3.3) recruited through online advertisements. Twenty participants were working professionals, and 12 were students. Participants were given a Google sheet containing demographic information such as their name, age, gender, occupation, and ethnicity. Each participant received a monetary reward of £10 for their participation. The top two high-performing teams received an additional monetary incentive of £80 and £40, respectively. All participants were treated ethically according to the current organisation's ethics norms.

3.3 Research Questions and Hypotheses

This study design explores understanding the fine relationship between varying levels of induced stress and individual performance, aiming to identify the factors that significantly influence individual performance under induced stress. Simultaneously, it focuses on team dynamics, exploring how an individual's performance under stress influences team coordination and collaboration in high-pressure situations. Within this context, the research questions also aim to identify the key elements contributing to successful teamwork within challenging circumstances, winding together the intricate interplay between individual stress responses and their collective impact on team dynamics and performance outcomes.

1. **Time Pressure Impact:** We aim to replicate a set of results from previous studies, which found an overall small but detrimental effect of time pressure on performance. Under time pressure, People process information more quickly (Benson III and Beach, 1996; Payne et al., 1988) and become more energetic and anxious (Maule et al., 2000). Much of the research shows that time pressure negatively affects decision-making, making people give more weight to negative information, which leads to a worse outcome.

2. **Influence of Individual Performance:** We assert that individual performance is not isolated but influenced by the accomplishments of other participants. This hypothesis explores the interconnected nature of individual performances within the experimental setting.

3. **Implicit Coordination and Team Performance:** Building on earlier research, we hypothesize that implicit coordination is linked to improved team performance (Butchibabu et al., 2016). Low-performing teams are expected to engage in explicit communication more frequently than high-performing teams, highlighting the role of coordination strategies in team effectiveness.

4. **Anticipation Ratio in Team Performance:** High-performing teams are anticipated to exhibit a superior anticipation ratio compared to low-performing teams (Serfaty et al., 1993). This hypothesis aims to explore the relationship between team anticipation skills and overall team performance.

3.4 Study Design

Two tasks were designed, the first to measure individual performance and the second to measure team dynamics. These tasks are designed so that the experiment can be carried out remotely. Thus, these tasks were designed on Google Sheets, which participants could access in real time from any location. All participants were able to view and edit the sheet.

3.4.1 Background Measures

The **Perceived stress scale** was used as a background measure to understand participant stress levels when participating in the study. The Perceived Stress Scale (Cohen et al., 1983) is the most widely used psychological instrument for measuring the perception of stress. It measures the degree to which situations in one's life are appraised as stressful. The PSS includes questions about feelings and thoughts during the last month. Respondents were asked how often they felt a certain way in each question. The answers are graded on a five-point Likert scale ranging from 1 (never) to 5 (often). Scores on the PSS can range from 0 to 40, with higher scores indicating higher perceived stress.

1. Scores ranging from 0-13 would be considered low stress.
2. Scores ranging from 14-26 would be considered moderate stress.
3. Scores ranging from 27-40 would be considered high perceived stress.

3.4.2 Individual Expertise Measurement Task

Figure 3.2 illustrates the task design specifically prepared for evaluating individual performance under time pressure. The design was implemented using an editable, shared Google Spreadsheet. The spreadsheet was organized into blocks distinguished by four distinct colours. Each colour category comprised blocks numbered consecutively from 1 to 80, culminating in a total of 320 blocks. Four participants engaged simultaneously in the task, each allocated a specific colour category. Participants executed the task within designated empty columns adjacent to the task design blocks.

Task Execution Procedure: Participants were guided to manipulate the coloured blocks using standard keyboard commands—cut (Ctrl+x) and paste (Ctrl+v). The objective was to arrange the blocks in ascending numerical order within their respective columns, adhering to a fixed time frame of 5 minutes. For instance, a

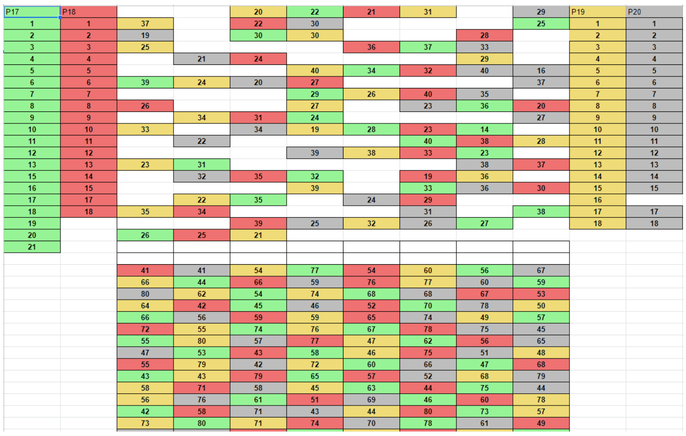

FIGURE 3.2: Individual performance measurement task: utilizing a numbered, color-coded Google Spreadsheet for individual performance measurement under induced stress, enabling simultaneous participation.

participant assigned the "green" category would initiate by selecting and placing the block labelled "1" from the green category into their designated column, followed sequentially until the time limit expired. Regular time updates were communicated to participants throughout the task duration.

Experimental Constraints and Phases: Given the online nature of the experiment and time limitations, a concurrent multi-participant setup was employed, accommodating up to four participants concurrently. Each participant, despite simultaneous engagement, performed the task independently. Explicit time constraints were implemented to measure performance under varying pressures, understanding the experiment into three distinct phases:

1. Phase 1: Conducted without time constraints.
2. Phase 2 and 3: Enforced time constraints to evaluate performance efficiency and expertise.

To intensify time pressure, periodic reminders were issued at specific intervals, and a countdown during the final 10 seconds ensured heightened quickness. Participants received time updates midway and one minute before task completion, eliminating external timekeeping tools to maintain uniformity..

3.4.3 Questionnaire for Individual Performance

To validate the study design assumptions, questionnaires were provided to participants after completing individual expertise measurement tasks. Most of the questions were related to the stress experienced during individual expertise measurement tasks. The items are introduced with *"To what extent do you think . . .".* A copy of this questionnaire is included in Appendix 2. The answers are graded on a five-point Likert scale that ranges from 1 to 5.

Q1: To what extent do you think that time pressure makes you stressed?

Q2: To what extent do you become stressed while watching other participant's performances?

Q3: To what extent do you think you did not have enough time to complete everything?

Q4: To what extent do you think you were having trouble completing tasks in a given time?

Q5: To what extent do you think this task makes you sensitive and irritable?

Q6: To what extent do you think this task makes you stressed?

3.4.4 Team Performance Measurement Task

Figure 3.3 presents a task design tailored to assess team performance by measuring the influence of individual expertise on team performance. Intractable to enabling competitive dynamics among participants, the task highlighted collaborative participation among team members. The division of participants into teams depends upon individual expertise levels derived from prior individual performance tasks. All 32 participants were strategically divided into eight teams, ensuring each team comprised four members.

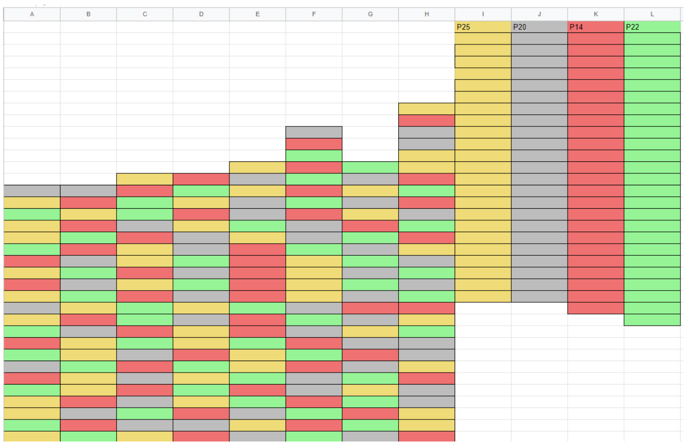

FIGURE 3.3: Team performance measurement task: using a colour-coded Google spreadsheet for block arrangement to understand team performance under induced stress, facilitating simultaneous participation of four participants.

Task Execution Procedure: Each team accessed a dedicated Google Sheet, illustrated in Figure 3.3, housing a cumulative 672 blocks distributed across four distinct colours. In contrast to individual tasks, these blocks were devoid of numerical labels. Participant roles were delineated based on colour assignments within the team. The task's temporal boundary was uniformly set at 5 minutes, during which participants navigated specific procedural guidelines. Participants could extract only one block at a time, contingent on the predecessor block's vacancy. The task's design necessitated interdependent actions, fostering collaborative engagements. Participants could seek assistance or interact collaboratively to overcome challenges.

Experimental Constraints and Phases: To simulate real-world conditions and assess adaptability, the experiment integrated auditory distractions and temporal pressures. Time management was centralized, prohibiting individual timekeeping devices and introducing periodic temporal reminders. Explicit countdowns during the final 10 seconds intensified performance pressures.

1. Phase 1: Conducted without time constraints.
2. Phase 2 and 3: Infused with temporal pressures, evaluating adaptability and performance under constrained conditions.

Performance matrices were formulated based on teams' cumulative block removals within the stipulated 5-minute window. These block removals were interpreted as performance scores, facilitating the categorization of teams into high-performing and low-performing clusters. Enhanced scores substantiated superior team dynamics and collaborative efficacy.

3.4.5 Questionnaire for Team Dynamics

To validate the study design assumptions, questionnaire two was provided to participants after completing the team coordination task. Most of the questions were related to the stress experienced during the study. A copy of this questionnaire is included in Appendix 2. The answers are graded on a five-point Likert scale that ranges from 1 to 5. The items are introduced with *"To what extent do you think . . ."*
Q1: To what extent do you feel time pressure makes you stressed?
Q2: How successful do you believe you completed the task we assigned, and how satisfied were you with the results?
Q3: To what extent do you feel insecure? Discouraged. Irritated. And annoyed?
Q4: To what extent do stranger team members make you stressed and less confident in completing the task?
Q5: To what extent do you feel the task was easy?
Q6: To what extent do you feel you were able to coordinate with team members?
Q7: To what extent do you feel in your group other members are weak players?
Q8: To what extent do you feel you can perform better in a laboratory-based environment?
Q9: To what extent do you believe receiving a reward for a winning team will encourage you to complete a task properly?

Q10: To what extent do you feel comfortable in recording tasks?
Q11: How stressful do you find auditory distraction and researcher interference during a task?
Q12: To what extent do you feel the first experiment session helped you to complete the second experiment more efficiently?
Q13: To what extent do you believe that having an agent to support you in selecting the appropriate cell will benefit you in completing tasks more quickly?

3.4.6 NASA-TLX:

Along with Questionnaire 2, the NASA TLX form was also provided to the participants after completing the team coordination task. The NASA Task Load Index (NASA-TLX) gathers workload data remotely. NASA-TLX is a widely used subjective, multidimensional assessment tool that rates perceived workload in order to assess the effectiveness of task, device, or team (Hart, 2006). The NASA TLX provides an overall score based on a weighted ratings average. The five sub-scales are described below:

1. Mental Demands - How mentally fatiguing was the task?
2. Overall Performance - How successful were you in accomplishing what you were asked to do?
3. Physical Demands - How physically fatiguing was the task?
4. Temporal Demand - How hurried or rushed did you feel during the task?
5. Effort - How hard did you work to accomplish your level of performance?

3.5 Results

In this section, we present the experiment's outcomes, which were explained in the previous section. The data analysis was conducted using the R programming language. In the subsequent sections, we provide a comprehensive summary of the research findings based on our analysis, keeping a statistical significance threshold set at $\alpha = 0.5$ before any corrections.

3.5.1 Perceived Stress Scale

Before the task, participants' perceived stress levels were assessed. Figure 3.4 depicts the Distribution of Perceived Stress Scale (PSS) Scores among 32 Participants. As shown in Figure 3.4, The majority of participants reported low levels of perceived stress (62.5%), while a substantial proportion reported moderate stress (31.25%). Only a small percentage of participants indicated high levels of perceived stress (6.25%). This distribution suggests that the study population, on the whole, experiences relatively low levels of perceived stress.

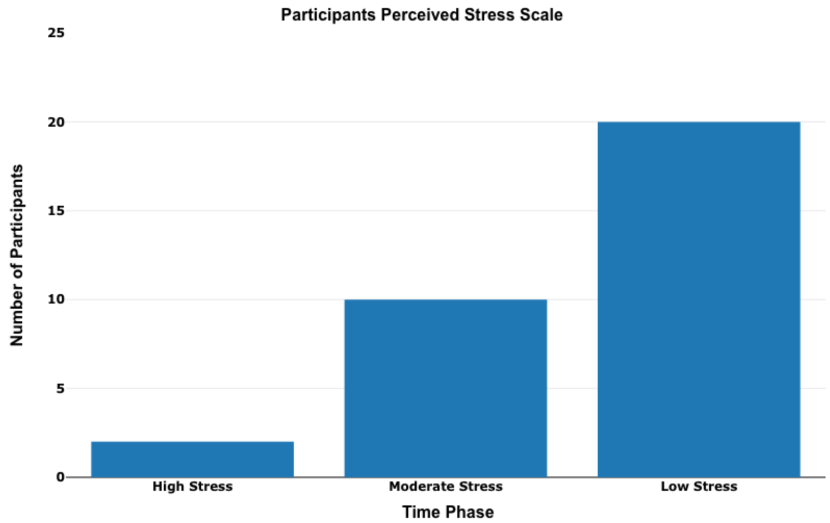

FIGURE 3.4: Distribution of participants' low, medium and high-stress levels in Perceived Stress Scale analysis.

3.5.2 Individual Expertise Measurement

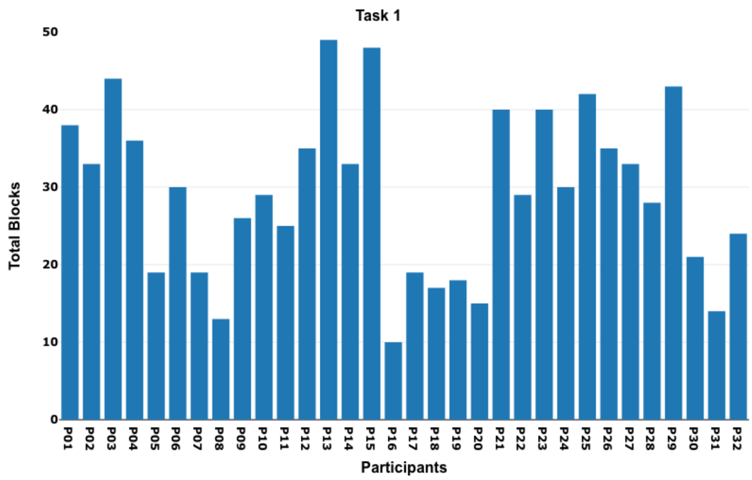

FIGURE 3.5: Histogram illustrating individual participants' block removal in the Individual Expertise Measurement Task performance assessment.

The first task was designed to determine the effect of time pressures on individual performance. Figure 3.5 shows the total number of blocks removed by all 32 participants in 5 minutes. The average time to remove each block taken by all participants in two separate time phases is given in Table 3.1. Figure 3.6 depicts the difference in time required to remove one block across all 32 participants in two distinct time pressure phases. Phase one is considered non-stressful, while phase two is considered stressful.

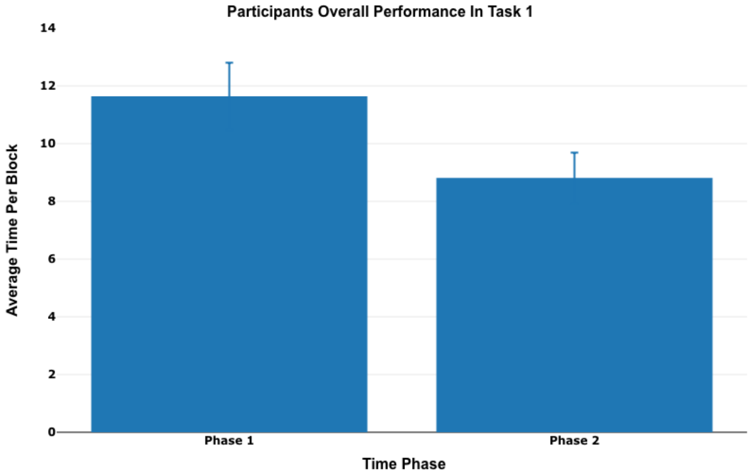

FIGURE 3.6: Comparison of average blocks removed by participants in phase 1 and phase 2, analyzing participants' performance in individual performance tasks.

An unpaired two-sample Wilcoxon test compared the average time per block during phases one and two. A statistically significant difference existed between the two time phases ($p < .0003$). Additional posthoc tests revealed that time per block during phase one (M = 7s, SD = 13.1s) was considerably longer than during phase two (M = 6s, SD = 9.4s). These findings suggest that time pressure-based induced stress positively impacts individual performance. Participants were given a questionnaire to validate the assumptions of the individual expertise measurement task. According to the survey results, participants indicated that time constraints increased stress, but the results show that it helps them perform better.

TABLE 3.1: Average time comparison between phase 1 and phase 2 taken by all participants in individual performance measurement task.

Phase	Average Time (In Seconds)
Phase 1	11.64
Phase 2	8.81

3.5.2.1 Questionnaire for Individual Performance Analysis

We conducted a thorough distribution analysis of the responses provided by the participants in our questionnaire. The results of this analysis are depicted in Figure 3.7, which illustrates the participants' responses to the questions related to the measurement of individual expertise. In this plot, the X-axis corresponds to the specific questions posed in the questionnaire, while the Y-axis represents the corresponding ratings provided by the participants. This graphical representation is a valuable resource for gaining insights into how participants responded during the task, thereby contributing to the validation of the task itself.

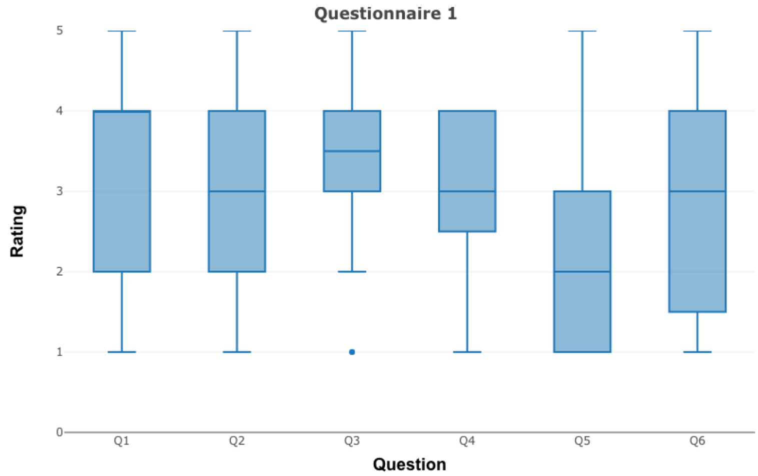

FIGURE 3.7: Box plot analysis of individual performance measurement questionnaire responses.

3.5.3 Team Performance Measurement

The second task was designed to determine the effect of time pressure on team performance. The total blocks removed by each team in 5 minutes is shown in figure 3.8. The average time taken to keep blocks at the assigned location by all teams in 2 distinct time pressure phases is given in Figure 3.9. Phase one is considered non-stressful, while phase two is considered stressful.

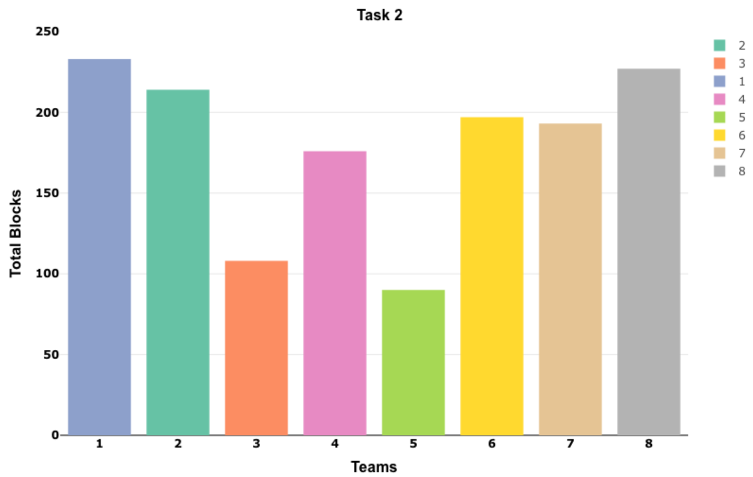

FIGURE 3.8: Histogram representation of total blocks removed by eight teams in team performance measurement task.

The average time taken to remove a single block in the time pressure phase is given in Table 3.2. The average time taken to remove the blocks increases in team performance tasks under time pressure. Figure 3.10 shows the average time taken by each team in

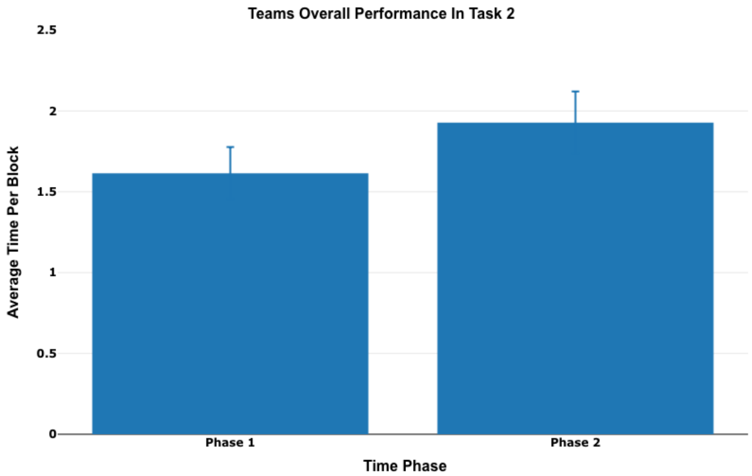

FIGURE 3.9: Comparison of average blocks removed by participants in phase 1 and phase 2, analyzing participants' performance in team performance measurement tasks.

two different time pressure phases. We used an unpaired two-sample Wilcoxon test to compare the average time per block during phases one and two. We found a statistically significant difference between the two time phases ($p < .015$). Additional post-hoc tests revealed that time per block during phase one (M = 1s, SD = 1.50s) was considerably shorter than during phase two (M = 1.2s, SD = 1.72s). These findings suggest that time pressure-based induced stress hurts team coordination. In the questionnaire analysis, participants indicated that time pressure made them stressed. They were not able to coordinate with fellow team members. Overall, a team's performance is negatively impacted by time pressure. Participants also mentioned auditory distraction and experiment organizer interference increases stress. According to the NASA TLX analysis, participants indicated this task was cognitively challenging and felt hurried or rushed.

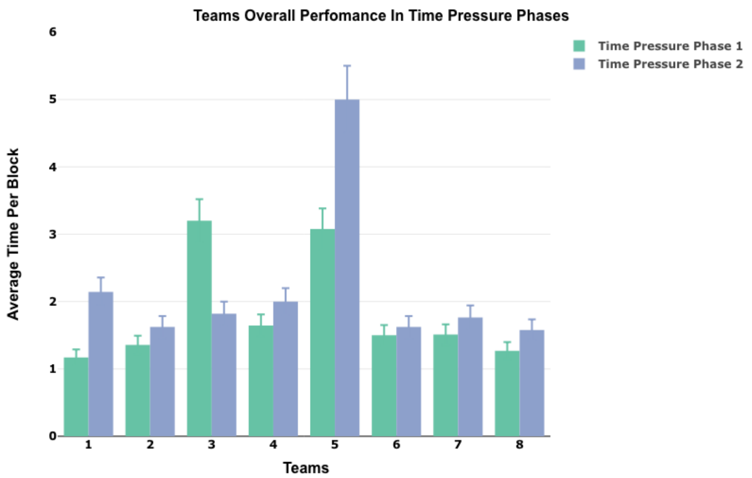

FIGURE 3.10: Histogram illustrating average number of blocks removed by eight teams in phase 1 and phase 2 in team performance measurement task.

TABLE 3.2: Average time comparison between phase 1 and phase 2 taken by all teams in team performance measurement task.

Phase	Average time (In Seconds)
Phase 1	1.61
Phase 2	1.92

TABLE 3.3: Transcription of Team One's audio communication converted into text.

Sec	Transcribe	Events
20	**(P09):** Yellow C	
40	**(P10):** C1 C Please, **(P12):** D1, D Green	
60	**(P09):** A Green, **(P12):** F Yellow	
80	**(P12):** F Yellow	
100	H Green Please, Its Green	
120	.....	
140	Yellow F Thanks	
160	**(P09):** Sorry, I am ..., **(P12):** G Yellow Please	
180	**(P10):** H Red please, **(P09):** Yes, **(P09):** Where is H block, Red yes yes	
200	**(P09):** Just a minute, **(P10):** H gray please, yes got it got it,**(P09):** I need to move screen too much	
220	Everyone laughing **(P12):** Move Red **(P09):** Yes, **(P04):** Can we select multiple colours	**(Researcher):** No one at a time
240	**(P09):** I just did it before you said, **(P09):** I had already presses it	**(Researcher):** No no don't cut all, **(Researcher):** I already told you
260	**(P09):** I have a problem the screen is too small **(P010):** C Red Please, **(P04):** C Yellow	**(Researcher):** You have one minute left
280	**(P12):** G Red, **(P09):** Ahh sorry	**(Researcher):** 30 second left
300	**(P04):** I know you are lying about time, C Green	**(Researcher):** 5 second, 4, 3, 2, 1, Stop

3.5.3.1 Questionnaire for Team Performance Analysis

We conducted a detailed distribution analysis of their responses to gain a deeper understanding of the data collected from participants. The outcomes of this analysis are visually represented in Figure 3.11, which provides a comprehensive view of the participants' responses to Task 2. In this graphical representation, the X-axis corresponds to the questions presented in the questionnaire, while the Y-axis reflects the ratings assigned by the participants. This visual representation offers valuable insights into how participants rated Task 2, enhancing our comprehension of their perspectives and responses.

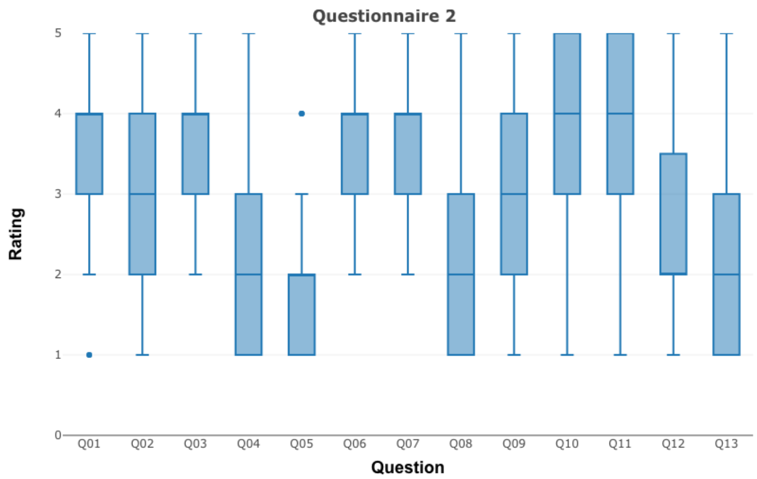

FIGURE 3.11: Box plot analysis of team performance measurement questionnaire responses.

3.5.3.2 NASA-TLX Analysis

We carried out a comprehensive distribution analysis of the NASA TLX responses to gain deeper insights into the workload experienced by participants. The results of this analysis are presented visually in Figure 3.12, which provides a detailed overview of the workload outcomes. In this graphical representation, the X-axis categorizes the different types of workload, while the Y-axis quantifies the corresponding ratings provided by the participants. This graphical depiction serves as a valuable resource for interpreting the workload experienced by participants, enhancing our understanding of the data collected during the NASA TLX analysis.

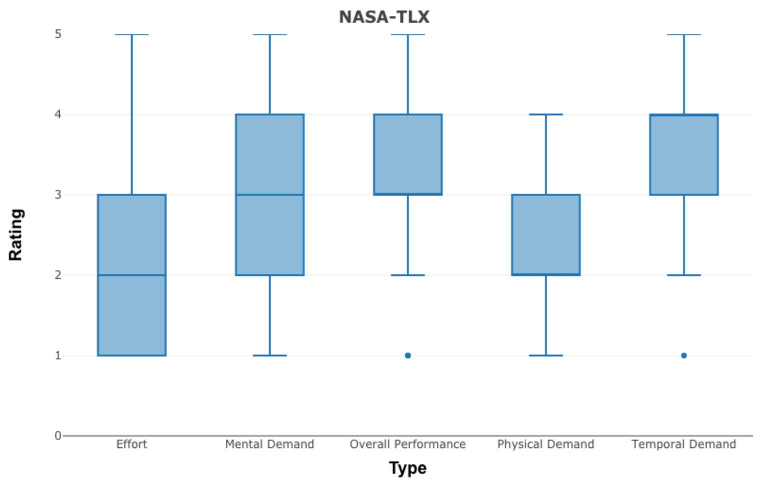

FIGURE 3.12: Box plot analysis of NASA-TLX responses for overall team performance.

3.5.4 Evolved Coordination Tactics in Teams

The number of blocks removed by each team in a given time was used to measure team performance, which was clearly conveyed to participants as part of the study protocol. According to previous literature, an independent researcher characterised team coordination behaviour from the experiment as either implicit or explicit coordination. Explicit communication comprised of (a) commands intended to control teammates' future actions and (b) prompts or requests for information (Entin and Serfaty, 1999). The offering of anticipatory information that another team member might find helpful and the communication of status updates about observation (Serfaty et al., 1993) are examples of implicit communication. Overall, all eight teams showed higher rates of implicit communication (M = 0.05, SD = 0.02) than explicit communication (M = 0.04, SD = 0.01).

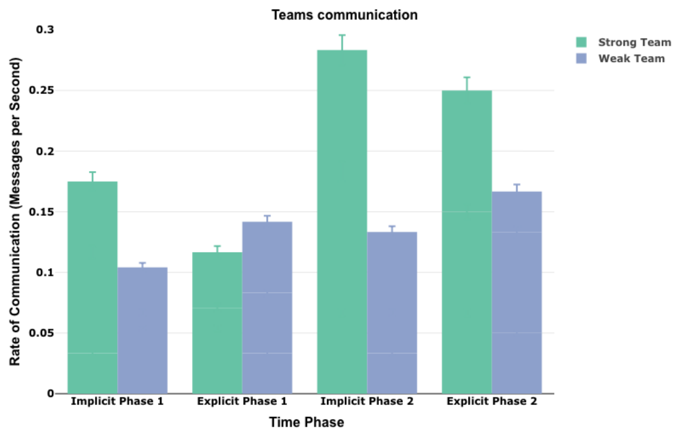

FIGURE 3.13: Rate of implicit and explicit communications in the top three strong teams and bottom three weak teams in Phase 1 and Phase 2.

The first three teams with the quickest completion time had a significantly faster average time in removing the block than those with the most extended completion times. Communication analysis compared the fastest three teams to the slowest three teams. Participant combined performance for both tasks are analysed, and the tasks have been transcribed in the 20-second window to see the communication impact of performance Table 3.3. Teams with members that proactively communicated information about their next goal to team members outperformed others. Team coordination strategy evolved from explicit coordination under low pressure to implicit coordination as pressure increases. Individual attention moves from a wider to a narrower state while under stress. In both time phases, the top three teams exchanged implicit communication at a higher rate than the bottom three teams; additionally, the top three teams' rate of implicit communication increased significantly under time pressure, as shown in Figure 3.13.

3.6 Validation of Previous Studies

This section aims to compare the findings and methodologies of this study with those of prior research in human ergonomics. Through this comparison, we seek to validate our findings and highlight both consistencies and contradictions within the broader scientific discourse. Previous research concerning the influence of stress on performance has identified three dimensions of task structure that contribute to overall task complexity: component complexity, coordinative complexity, and dynamic complexity Butchibabu et al. (2016). Our study has addressed all these dimensions. By examining the intricate dynamics of stress, performance, and coordination, we aim to explicate the factors that significantly influence outcomes in high-pressure situations. This comparison seeks to validate our study's contributions to the field and explore consistencies and contradictions within the existing body of knowledge. Table 4.3 presents a summary of previous studies that examine the impact of stress on performance, offering a direct comparison with our findings. Within this chapter, our focus is on examining component complexity and coordinative complexity. This research builds upon an established practice where practical knowledge from psychology is applied to develop training programs aimed at enhancing team coordination (Ford, 2014; Helmreich et al., 2017). Compared to the seminal work of Abhizna (Butchibabu et al., 2016), which utilized varying degrees of complexity in the task to understand the team's performance. Our work represents the first step towards understanding the performance of the same participants in both individual and team-based tasks, and the tasks we design based on component complexity and coordinative complexity are novel. In our study, we hypothesize that time pressure will have a detrimental impact on both individual and team performance. Drawing on previous research (Kahneman and Tversky, 1979; Keinan and Melamed, 1987), which indicates that individuals under time pressure process information more quickly and experience heightened energy levels, our experimental results align with this, demonstrating an increase in individual performance under time pressure. According to the survey results, participants indicated that time constraints increased stress, but the results show that it helps them perform better. However, the adverse effects on team performance were evident, as teams struggled to coordinate effectively and took longer to complete tasks when subjected to time pressure. Overall, team performance is negatively impacted by time pressure. From the previous study on explicit coordination from (Espinosa et al., 2004; March and Simon, 2005; Hinds and Bailey, 2003) and implicit coordination (Faraj and Xiao, 2006; Klimoski and Mohammed, 1994) have mentioned implicit and explicit coordination tactics in the team. Based on the literature and our hypothesis regarding different time pressures, our investigation into implicit and explicit communication within teams revealed that eight teams exhibited higher rates of implicit communication than explicit communication. Moreover, our analysis showed that faster teams engaged in significantly more implicit communication than slower teams, highlighting the importance of implicit coordination, particularly under time pressure.

Table 3.4: Studies examining the impact of induced stress on performance

Study	Category	Partici-pants	Task/Stressor	Main results	Comparison with Our Findingss
(Keinan and Melamed, 1987)	Dysfunctional strategy use	Students 42 m/59 f	Analogies/Threat of electric shock	Stress led to decreased performance and non-systematic scanning of alternatives.	Contrasts with our findings, where induced stress under certain conditions improved individual performance due to heightened focus and quicker information processing.
(Starcke et al., 2008)	Decision-making under stress	Students 18 m/22 f	GDT/Anticipated speech	Stress led to more disadvantageous choices, with cortisol reactions correlated to risky decisions.	Our results add complexity, showing that stress impacts decision-making differently across individual and team contexts, with team performance suffering more than individual performance.
(Kassam et al., 2009)	Insufficient adjustment from automatic response	32 m/71 f	Anchoring and adjustment/-Modified TSST	Stress led to a decrease in adjustment and stress responses predicted decreased adjustment On gain domain trials, stress led to more conservative choices, on loss domain trials, stress led to more risky choices.	Aligns with our observations on stress affecting strategic adjustments, particularly in team coordination tasks where pressure impeded effective communication and task execution.
(Putman et al., 2010)	Insufficient adjustment from automatic response	Students 29 m	Modified CGT/Application of cortisol	Stress led to more risky decisions whenever the potential reward was high.	Supports our findings where time pressure-induced stress improved individual performance, suggesting a nuanced relationship between stress and risk-taking behavior.
(Youssef et al., 2012)	Insufficient adjustment from automatic response	Students 30 m/35 f	Moral dilemmas/TSST	Stress led to fewer utilitarian judgments in personal dilemmas. Stress responses and nonutilitarian judgments were correlated.	Offers a complementary perspective to our study, indicating how stress can influence decision-making frameworks, extending beyond performance to moral reasoning.
(Driskell and Salas, 1991)	Altered feedback processing	Students 78 m	Team decision making in an ambiguous checkerboard-/Announced tear gas drill	Stressed participants more strongly relied on the judgments of other persons.	Mirrors our findings on the impact of stress on team dynamics, where increased stress hindered effective coordination and led to reliance on implicit communication strategies.
(Butchibabu et al., 2016)	Coordination in teams	Students 41 m/11 f	Search-and-deliver tasks within a synthetic task environment/Blocks World for Teams	Higher rates of implicit coordination than explicit coordination. All teams uses deliberative communications at higher rates.	Reflects our results on the evolution from explicit to implicit coordination under stress, underscoring the role of anticipatory information sharing in high-performing teams.

Teams with members that proactively communicated information about their next goal to team members outperformed others. Team coordination strategy evolved from explicit coordination under low pressure to implicit coordination as pressure increases. Individual attention moves from a wider to a narrower state while under stress (Driskell and Salas, 1991). In both time phases, the top three teams exchanged implicit communication at a higher rate than the bottom three teams. This finding from our work can inform the design of communication strategies for teams aiming to improve performance in complex tasks. Additionally, we found the impact of social comparison on individual performance based on (Wheeler, 2000); our finding shows that participants' performance was influenced by the performance of their counterparts, either positively, as they aspired to match high-performing individuals or negatively, as they became discouraged by perceived performance gaps. Lastly, In team performance, the anticipation ratio can be used to gauge the team's ability to plan and prepare tasks. If a team has a high anticipation ratio, it suggests they have a solid capacity to anticipate and address task needs (Sexton et al., 2017). In contrast, a low ratio may indicate that the team struggles to plan effectively. We compared the anticipation ratio between high-performing and low-performing teams. Our analysis indicated that the fastest teams exhibited a higher anticipation ratio than the slowest teams.

3.7 Summary

Our experimental tasks, designed to measure individual and team performance under time pressures, revealed a consistent pattern. Time pressure exerted a detrimental impact on both individual and team performance. Notably, the anticipation ratio emerged as a valuable metric, showcasing high-performing teams' superior planning abilities. Top-performing teams displayed a preference for implicit coordination over explicit coordination under time pressure, highlighting the significance of adaptive communication strategies. Communication rates increased for both high and low-performing teams under time constraints, emphasizing the crucial role of task-related communication in managing actions effectively. These findings underscore the intricate dynamics of team performance in high-pressure scenarios.

Chapter 4

Understanding Human Performance with Automated Agents

In the previous chapter, we explored the significant impact of induced stress on individual performance and team coordination, offering valuable insights and strategies for enhancing performance in high-stress scenarios. In the current chapter, our focus shifts towards the study design concerning human performance in the presence of automated agents. We will explore various facets, including task design, participant details, the experimental protocol, utilization of NASA-TLX, questionnaire analysis, background measures, and results. Section 4.1 provides detailed information about the method with an overview, participant information, and protocol. Section 4.2 offers research questions with hypotheses being investigated. In Section 4.3, we explain the study design, which includes background measures, individual performance measurement tasks with automated agents, NASA-TLX questions, and a questionnaire for individual performance with automated agents. Section 4.4 provides insights into the results of the Perceived Stress Scale measurements, unravelling the psychological impact of stress on participants' performance, NASA-TLX analysis, questionnaire analysis, performance with slow automated agents, and performance with fast automated agents. Section 4.5 briefly summarizes the key insights gleaned from the entirety of this chapter.

4.1 Method

In this study, we aimed to explore how automated agents influence individual performance. This experiment was conducted in a lab-based environment. Our main objective was to gain a comprehensive understanding of the impact of these agents on human performance. To achieve this, we designed a unique single-user task that was carefully crafted to ensure a seamless interaction between automated agents and participants. These experiments were conducted with meticulous attention to detail to uncover the intricate effects of automated systems on individual performance. After completing the task, participants were subjected to a NASA-TLX assessment, and we administered a comprehensive questionnaire to gather in-depth insights into their experiences and perspectives. As a crucial component of our research methodology, we used the Perceived Stress Scale as a background measure. This tool allowed us to assess participants' stress levels precisely during their study participation, providing valuable contextual information for our investigations. For the task design in this study, we harnessed the capabilities of Microsoft Excel, utilizing Macro and Visual Basics to create a sophisticated automated system. This system faithfully replicated the task participants were required to complete, offering the flexibility to simulate the task at both slower and faster speeds. This design choice was pivotal in enabling us to thoroughly examine how automated agents impact individual performance across varying levels of task complexity and time constraints.

4.1.1 Overview

This study explores the influence of automated agents and induced pressure on individual performance. Participants engaged in the study individually, with the opportunity to observe the performance of automated agents. As participants competed against slow and fast automated agents, they had the flexibility to adjust their strategies accordingly. Additionally, a three-time pressure phase and auditory distraction were introduced to investigate the effects of time pressure on overall performance. In summary, this research explores the impact of induced stress and automated agents on performance.

4.1.2 Participants

The participant pool comprised individuals representing diverse ethnic backgrounds and genders. A total of 38 participants were recruited through online advertisements to participate in this study. Those interested in participating were requested to complete a Google form, providing essential demographic information, including their name, gender, age, occupation, and ethnicity. Among the 38 participants, 13 were employed professionals, while 25 were enrolled as students. As a token of appreciation for their involvement in the experiment, each participant received a baseline monetary compensation of at least £10. Participants were provided an additional performance-based incentive of up to £10, depending on their task performance. Furthermore, a recognition was awarded to the participant who demonstrated exceptional performance, entailing an additional reward of £30. It is important to emphasize that all participants were treated strictly with the ethical guidelines established by our organization, ensuring the highest standards of ethical conduct throughout the study.

4.1.3 Protocol

The flow diagram of the experiment protocol is shown in Figure 4.1. There were 38 sessions total, each lasting about 30-40 minutes. Each participant received an overview of the task design, an introduction to the study, and an informed consent form. The overview included a demonstration of the Google Sheets display and instructions on completing the task.

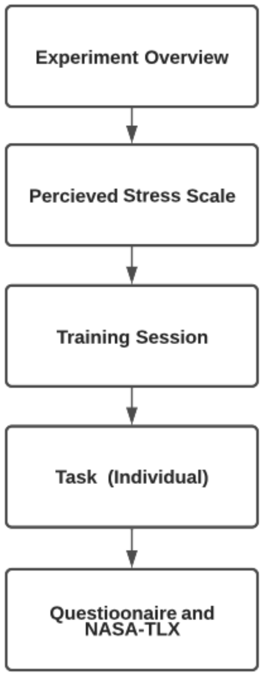

FIGURE 4.1: Illustrative flowchart depicting the sequential stages of the experiment, covering key components such as stress evaluation, training, task, and post-task assessments.

4.2 Research Questions and Hypotheses

This study is designed further to explore the impact of automated agents on individual performance, aiming to identify the factors that influence performance, including auditory distraction and the impact of reward and induced stress. Within the context, What strategies can optimize support in high-pressure situations involving both human and automated agents?

1. **Presence of Automated Agents:** The presence of automated agents operating at different paces will significantly influence individual performance under stress. Participants will adapt their strategies in response to the observed performance of these agents, resulting in measurable variations in task completion rates and stress levels.

2. **Induced Time Pressure:** The introduction of induced time pressure, combined with auditory distractions, will produce a measurable impact on individual performance in the task with automated agents. This will manifest in observable variations in task completion rates and levels of perceived stress among participants.

3. **Performance-Contingent Reward:** Introducing a performance-contingent reward system will positively influence individual task performance in the presence of induced stress and the involvement of automated agents, with an expected enhancement in motivation and effort among participants.

4.3 Study Design

A novel task has been developed to assess individual performance in the context of participants competing with automated agents. These tasks are structured to facilitate experimentation within a laboratory-based environment. The task uses macro and visual basics, allowing participants to access and interact with it in real-time. Participants had the opportunity to observe the real-time performance of automated agents during the experiment.

4.3.1 Background Measures

The **Perceived stress scale** was used as a background measure to understand participant stress levels when participating in the study. The Perceived Stress Scale (Cohen et al., 1983) is the most widely used psychological instrument for measuring the perception of stress. It measures the degree to which situations in one's life are appraised as stressful. The PSS includes questions about feelings and thoughts during the last month. Respondents were asked how often they felt a certain way in each question. The answers are graded on a five-point Likert scale ranging from 1 (never) to 5 (often). Scores on the PSS can range from 0 to 40, with higher scores indicating higher perceived stress.

1. Scores ranging from 0-13 would be considered low stress.

2. Scores ranging from 14-26 would be considered moderate stress.

3. Scores ranging from 27-40 would be considered high perceived stress.

4.3.2 Individual Performance Measurement Task with Automated Agents

Figure 4.2 illustrates the task design employed in this study to measure individual performance in the presence of induced time pressure and auditory distraction, as well as the comparison with slow and fast automated agents. A total of 32 participants took part in this study. Each participant was assigned a specific colour and instructed to perform the task on their empty columns. The remaining three columns were designated for three different automated agents. For half of the participants, the automated agents operated at a fast speed, while the other half operated at a slow speed. The performance of the automated agents was visible to each participant.

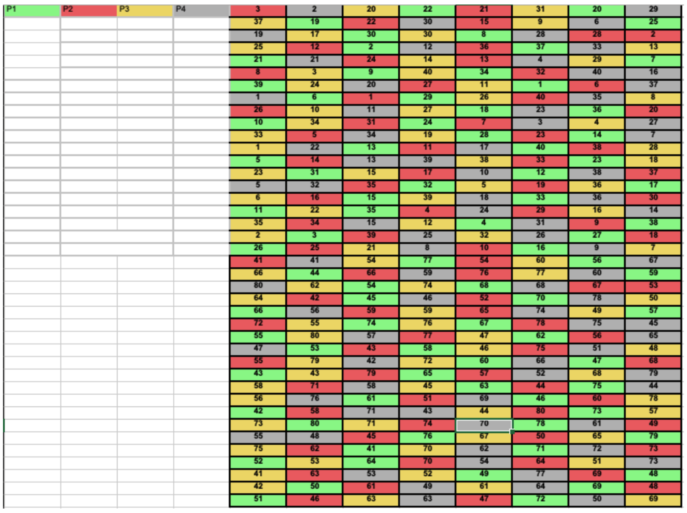

FIGURE 4.2: Task design for individual performance measurement, utilizing a numbered, color-coded Google Spreadsheet to evaluate performance while competing against automated agents.

The task sheet Figure 4.2 was randomly divided into blocks of four different colours, resulting in 320 blocks. Each block within a single colour category was numbered from 1 to 80, creating a set of 320 blocks in total. Participants were instructed to use the ”cut” command (Ctrl+x) to remove the coloured brick assigned to them from the bundle of colours and then use the ”paste” command (Ctrl+v) to place the brick in their assigned column, starting from the top and moving downward. The blocks were to be cut in ascending order, beginning with 1.

The task duration was fixed at 6 minutes, during which participants were required to fill their assigned columns with as many blocks as possible within the given time frame. For instance, a participant would locate the green-coloured brick labelled ’1’ and paste it into their P1 column. They would then proceed to find the green-coloured brick labelled ’2’ and continue pasting it in their column, and so on, until the time expired. Throughout the task, the participants were periodically informed about the remaining time to complete the task. Individual performance was measured by the number of blocks each participant removed within the 6-minute time limit. Participants were informed that their participation reward could increase from £10 to £20 if they outperformed the automated agents, and the highest-performing individual would receive an additional reward of £30. This setup aimed to induce performance pressure based on the potential reward. In summary, this task design involved participants performing a block-cutting and pasting task within a time-constrained environment while competing against automated agents operating at different speeds. Individual performance was evaluated based on the number of blocks removed within a 6-minute time limit.

4.3.3 NASA-TLX Questions

1. How mentally demanding was the task?
2. How physically demanding was the task?
3. How successful were you in accomplishing what you were asked to do?
4. How hard did you work to accomplish your level of performance?
5. How insecure, discouraged, irritated, stressed, and annoyed were you?

4.3.4 Questionnaire for Individual Performance with Automated Agents

1. To what extent do you feel that time pressure at the end of the task makes you feel stressed?
2. To what extent do you become stressed while watching the performance of another automatic agent?
3. To what extent do you feel you did not have enough time to compete with the agent?
4. To what extent do you feel you had difficulty watching the other screen for the agent's performance?
5. To what extent do you feel this task makes you sensitive and irritable?
6. To what extent do you feel this task makes you stressed?
7. To what extent do you believe receiving a reward for outperforming the agents will encourage you to take the task seriously?
8. To what extent do you feel the agents performed well in completing tasks?
9. Have you ever played or worked on a task similar to this?

4.4 Results

In this section, we present the experiment's outcomes, which were explained in previous section. The data analysis was conducted using the R programming language. In the subsequent sections, we provide a comprehensive summary of the research findings based on our analysis, keeping a statistical significance threshold set at $\alpha = 0.5$ before any corrections.

4.4.1 Perceived Stress Scale

Before the task, participants' perceived stress levels were assessed. Figure **??** depicts the Distribution of Perceived Stress Scale (PSS) Scores among 32 Participants. We examined how they perceived stress using the Perceived Stress Scale (PSS). What we found was that people's stress levels varied quite a bit. About 6.25% of the participants felt a high stress level, and the same percentage felt low stress. The majority, which was 87.5% of the group, reported feeling a moderate level of stress. These results show that people in our study experienced stress differently, highlighting the importance of providing specific support to address their stressors.

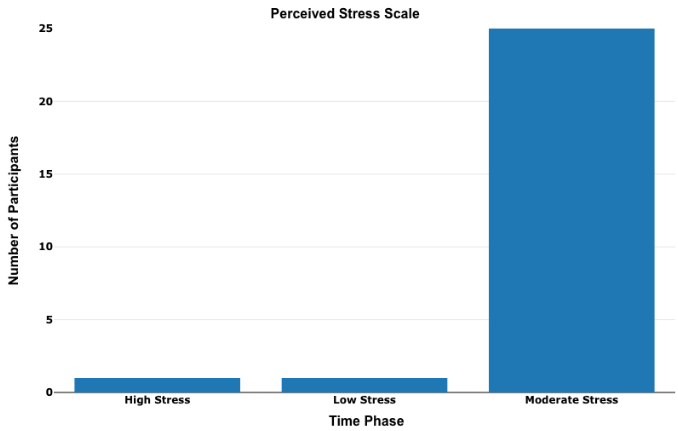

FIGURE 4.3: Distribution of participants' low, medium and high-stress levels in perceived stress scale analysis.

4.4.2 Individual Performance Measurement

Individual expertise was measured by the number of blocks removed by each participant in a 6-minute time limit. Participants were instructed not to use a watch while experimenting. They were informed about the remaining time during the task: once after 2 minutes and a second in 4 minutes had passed, and again when one minute remained. The experiment organizer counted the last 20 seconds to place participants under time pressures. The entire experiment was divided into three time phases. The first phase was designed to be under no time pressure, the second phase was designed to be under moderate time pressure, and the third was under high time pressure. Figure 4.4 shows the total number of blocks removed by all 32 participants in 6 minutes.

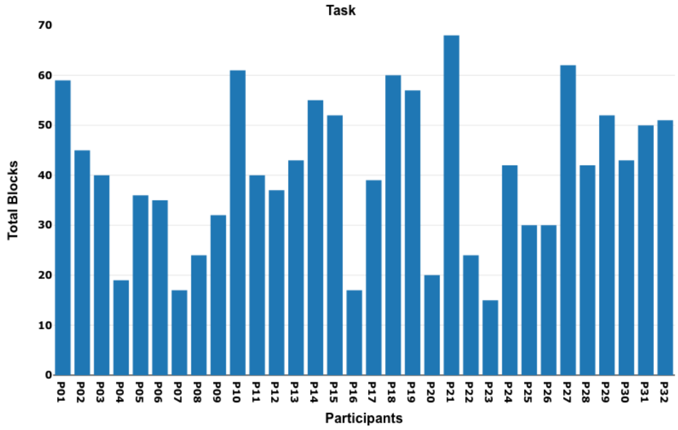

FIGURE 4.4: Histogram illustrating individual participants' total block removal in the individual performance measurement task performance assessment.

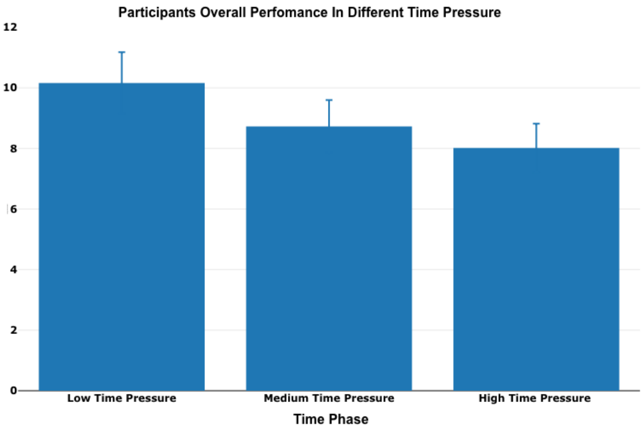

FIGURE 4.5: Comparison of average blocks removed by participants in Phase 1, Phase 2, and Phase 3, analyzing participants' performance in individual performance tasks under induced stress.

All 32 participants' performance was divided into 3-time pressure phases. Figure 4.5 shows all participants' average time to find and remove the block in 3 distinct time pressure phases. As can be seen, the Figure 4.5 average time taken to remove the blocks is decreased under time pressure. Table 4.1 shows the average time taken by all participants in two separate time phases to remove each block. As a consequence of time pressure, the performance differed significantly. The difference in time between the third and first phases is statistically significant. Participants' performance increased under time pressure. They were able to remove blocks faster under time pressure. These findings indicated that time pressure-induced stress positively affected individual performance. Participants were given a questionnaire to validate the assumption of the individual expertise measurement task. According to the survey results, participants indicated that time constraints stress them out, but the results show that it helps them perform better.

TABLE 4.1: Average time comparison between phase 1, phase 2, and phase 3 taken by all participants in individual performance measurement tasks.

Phase	Average Time (In Seconds)
Phase 1	10.15
Phase 2	8.72
Phase 2	8.01

4.4.3 NASA-TLX and Questionnaire

The box plots for each dimension visually represent the data distribution. Figure 4.6 shows participants responsible for the task. In the Mental Demand dimension, the ratings were concentrated around the median of 4, indicating a relatively consistent perception of mental workload among the participants. The Physical Demand dimension showed a lower median rating, suggesting that the tasks imposed minimal physical demands. The Temporal Demand dimension exhibited a more comprehensive range of ratings, indicating variability in participants' perceived time pressure. In terms of overall performance, participants rated their performance across a range of values, with the median indicating a moderate level of perceived performance. The Effort dimension showed a moderate spread of ratings, indicating varying levels of perceived effort invested by participants.

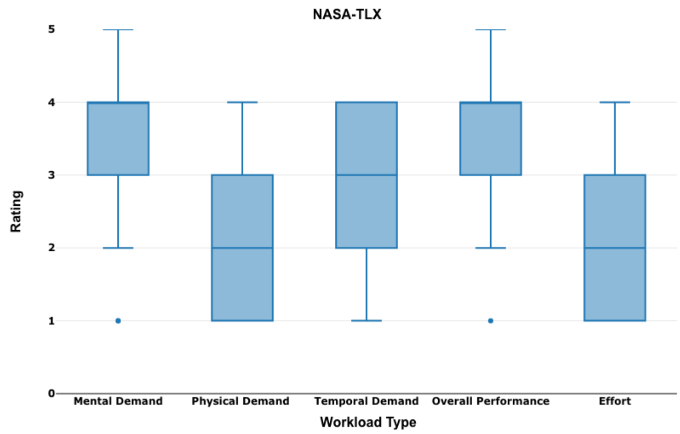

FIGURE 4.6: Box plot analysis of NASA-TLX responses for individual performance measurement.

These results provide insights into the perceived workload and task demands experienced by the participants. The findings suggest that the tasks involved moderate mental effort with relatively low physical demands. Time pressure and overall performance were perceived at a moderate level, while the level of effort invested varied among participants. The observed variations in the ratings highlight

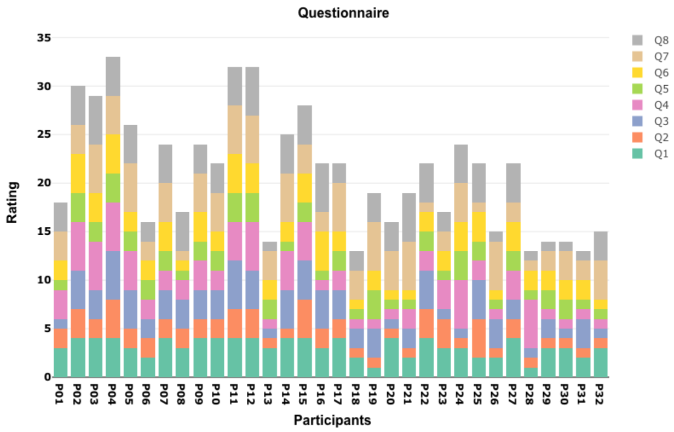

FIGURE 4.7: Histogram representation of questionnaire responses for individual Performance measurement.

the subjective nature of workload perception and underscore the importance of individual differences in responding to task demands. These findings contribute to our understanding of the cognitive and physical demands experienced during the tasks, providing valuable insights for designing interventions and strategies to optimize performance and manage workload effectively.

4.4.4 Performance With Automated Agents

Performance was assessed by measuring the number of blocks removed by each participant within a 6-minute time frame. The participants were divided into two groups: one collaborated with slow automated agents and the other with fast automated agents. Both groups were divided into slow, medium and high time pressure phases.

4.4.4.1 Performance with Slow Automated Agents

The study's objective was to investigate how the number of blocks removed by participants changed over three distinct 120-second time phases when participants competed with automated agents. A total of 16 participants took part in the experiment with slow agents, and the analysis focused on exploring the impact of these time phases on participants' performance as measured by the number of blocks removed. A repeated measures Analysis of Variance (rmANOVA) was conducted to examine the effect of different time phases on the number of blocks removed. The rmANOVA revealed a significant effect of time phase on the number of blocks removed, $F(1, 15) = 5.68$, $p < .005$, generalized eta-squared = 0.275. See Figure 4.8 for a histogram representation of mean blocks removed across different time phases. The effect size, measured by generalized eta-squared, was moderately large (0.80), indicating that approximately 27.5% of the variance in the number of blocks removed could be attributed to the time phase. This significant, large effect prompted further investigation through post-hoc tests to understand the nature of these differences across time phases. Pairwise comparisons were conducted using paired t-tests with Benjamini-Hochberg correction for multiple comparisons. The results indicated No significant difference between Phase 1 and Phase 2 ($p = 0.112$). Significant difference between Phase 3 and Phase 1 ($p < .001$). No significant difference between Phase 3 and Phase 2 ($p < .0541$). These results suggest that the number of blocks removed in Phase 3 was significantly higher than in Phase 1 and Phase 2. However, the number of blocks removed did not differ significantly between Phase 1 and Phase 2.

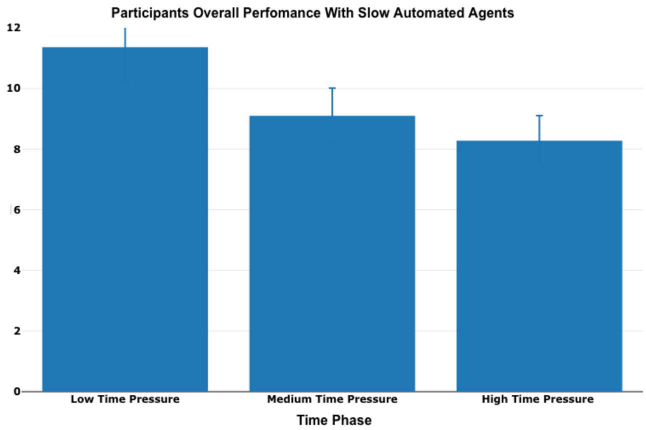

FIGURE 4.8: Comparison of average blocks removed by participants in low, medium, and high time pressure phases, analyzing participants' performance with slow automated agents.

The findings indicate that the time phase had a significant and large effect on the number of blocks removed by participants. Specifically, participants removed significantly more blocks in Phase 3 compared to Phase 1 and Phase 2. This could imply that participants became more efficient and experienced a change in strategy.

4.4.4.2 Performance with Fast Automated Agents

The study's objective was to investigate how the number of blocks removed by participants changed over three distinct 120-second time phases. A total of 16 participants took part in the experiment with fast agents, and the analysis focused on exploring the impact of these time phases on participants' performance as measured by the number of blocks removed.

A repeated measures Analysis of Variance (rmANOVA) was conducted to examine the effect of different time phases on the number of blocks removed. Contrary to expectations, the rmANOVA did not reveal a significant effect of the time phase on the number of blocks removed, $F(1,15) = 0.67$, $p = 0.42$, with a generalized eta-squared of 0.04 (See Figure 4.9 for a histogram representation of mean blocks removed across different time phases). The effect size, as measured by generalized eta-squared, was notably small (0.04), indicating that only approximately 4% of the variance in the number of blocks removed could be attributed to the time phase. Given the lack of significance in the primary rmANOVA, post hoc tests were also conducted to probe for possible pairwise differences. Pairwise comparisons were conducted using paired t-tests with Benjamini-Hochberg correction for multiple comparisons. The results indicated no significant differences between the phases (all p=0.6). These findings did not support the hypothesis that the time phase significantly affected the number of blocks removed by participants. This suggests that participants did not become significantly more or less efficient in removing blocks as the task progressed through different time phases. Future research may explore other variables or conditions that could impact the number of blocks removed during this task.

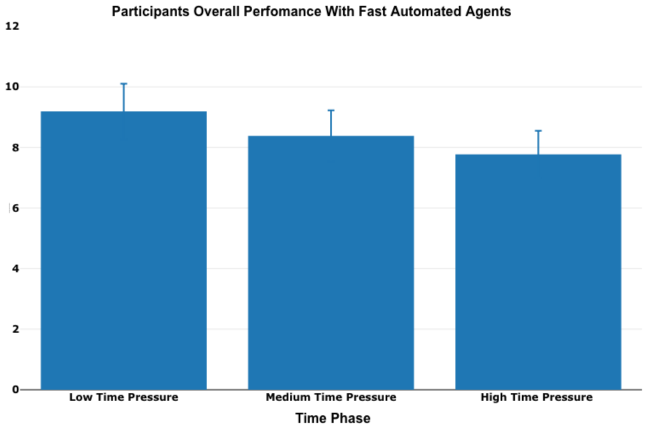

FIGURE 4.9: Comparison of average blocks removed by participants in low, medium, and high time pressure phases, analyzing participants' performance with fast automated agents.

The data suggest different behaviours in participants when interacting with slow and fast agents. For the slow agent condition, the time phase significantly impacted performance, although pairwise comparisons did not pinpoint where the differences lay. This indicates a more complex relationship requiring further investigation or a more fine analytical approach. In contrast, participants competing with fast agents showed no change in performance across time phases. This could suggest that the fast speed of the agents may not have allowed for adaptation or alteration in strategies by the participants.

4.5 Validation of Previous Studies

In response to the critical assessment of our initial approach to situating our research within the broader academic study, this section aims to establish a direct and rigorous comparison between our findings and those of preceding studies. Our investigation focuses on understanding the dynamics between automated agents, stress, and individual performance under time pressure, with a particular emphasis on understanding the role of fast and slow automated agents in time-pressure scenarios involving both human and automated agents. Table 4.5 Presents a summary of previous studies that examine the impact of stress on performance, offering a direct comparison with our findings.

Table 4.5: Studies examining the impact of stress on performance

Study	Category	Partici - pants	Task/Stressor	Main results	Comparison with Our Findings
(Mather and Lighthall, 2012)	Altered feedback processing	24 m/23 f	BART/CPT	Stress led to greater reward collection and faster decision speed in men, accompanied by activation of the dorsal striatum and anterior insula, but less reward collection and slower decision speed in women accompanied by decreased activation in the brain regions mentioned	Our findings do not delineate effects based on gender but rather highlight how automated agents influence decision-making under stress, suggesting a broader application of stress impacts across cognitive functions.
(Takahashi et al., 2007)	Altered reward and punishment	Students 31 m	Agents support	Stress led to more generous decisions in participants with stress reactions.	Contrasts with our results, where stress induced by automated agents led to more risk-averse behaviors, underscoring the complexity of automated influence on decision-making under stress.
(Stowers et al., 2020)	Condition based performance	Students 29 m/23 f/ 1 other	Anchoring and adjustment/-Modified TSST	Human operators may not fully comprehend and accommodate the inherent limitations of the agent's perception, reasoning, and projection. The agent's performance may vary depending on its environment and context, potentially resulting in less than optimal outcomes.	Aligns with our observations on the variability of automated agent impact on performance, emphasizing the need for adaptive interfaces.
(Manzey et al., 2012)	Automated aids	Engineering students 40 m /16 f	Supervisory control task	Automation improved fault management and identification performance. Higher automation levels correlated with increased benefits.AI support enhanced fault diagnosis and system stabilization.	Supports our findings on the positive impact of automated agents under certain conditions, indicating a nuanced interplay between automation level and stress impact on performance.
(Balfe et al., 2015)	Three level of automation	Working 6 m	Simulator	High automation reduces both mental and physical workload. Performance benefits are most consistent with high automation. Behavior differences highlight individual strategies during automation.	Echoes our results, suggesting that the speed of automated agents (a proxy for automation level) significantly affects participant performance, with faster agents not necessarily yielding better outcomes.
(Kshirsagar et al., 2019)	Real monetary incentives	Students 16 m/ 43 f	human-robot interaction in a monotonous competitive environment	Human-robot competition observed with minimal monetary influence.Participant preference and self-perception influenced by robot performance.	Our study, focusing on the non-monetary aspects of performance, such as stress and automated agent speed, provides a complementary perspective on human-automation interaction.

TThis section is intended to systematically compare the outcomes and methodological frameworks of the current study with those delineated in preceding research within the domain of human ergonomics. Based on our previous study on individual and team performance under time pressure. We hypothesize that automated agents and team members influence individual performance. It seeks to uncover practical approaches with automated agents to assist individuals in demanding situations and what strategies can optimize support in high-pressure situations involving human and automated agents. A study conducted by (Rieger and Manzey, 2022) explores the impact of time pressure on human performance with automated decision support systems. This contradicted their results, where they mentioned time pressure leads to negative performance. Our study unravels the intricate dynamics between automated agents, stress, and individual performance in time-pressure environments, offering nuanced insights that extend existing research. Contrary to conventional Insight, our findings indicate that heightened stress conditions and automated agents lead to a narrowed focus on immediate concerns, significantly impacting cognitive strategies and decision-making processes. This aligns with studies on stress-induced cognitive effects (Klein, 1996). Notably, individual performance, irrespective of participants' ability levels, is substantially influenced by the presence of automated agents, corroborating research by (Lee and Mihailidis, 2005). Our research extends the findings of (Mather and Lighthall, 2012) by exploring how the presence of automated agents affects decision-making under stress without a specific focus on gender differences. The contrast between our findings and those of (Takahashi et al., 2007) highlights the complexity of stress's impact on decision-making in the presence of automated agents, suggesting that the nature of the task and the characteristics of the stressor (e.g., automated agents vs. social stressors) significantly influence outcomes. The alignment with (Stowers et al., 2020) and (Manzey et al., 2012) underscores the nuanced relationship between human performance, stress, and automation. Our study adds to this discourse by providing detailed insights into how different speeds of automated agents can modulate this relationship, a factor not explicitly considered in these previous studies. The findings related to the impact of automation levels, as discussed by (Balfe et al., 2015), resonate with our observations regarding the differential effects of slow and fast automated agents on participant performance. This suggests that the level of automation, or in our case, the operational speed of automated agents, plays a critical role in shaping human performance under stress. Our results, exploring time pressure and agent speed in a block-removal task, reveal a complex scenario. Increased time pressure generally improves individual performance, echoing findings in (Singh et al., 2022). Intriguingly, divergent effects of agent speed suggest that detailed considerations are essential. Our research contributes to understanding the competitive dynamics introduced by automated agents, reinforcing the need for further investigation into the impact of time pressure and auditory distraction. Notably, we advocate exploring the interplay between physiological signals and performance outcomes. Identifying divergent effects based on agent speed resonates with the complexities highlighted in (Daronnat et al., 2020). Our research addresses current gaps and serves as a bridge to future investigations that comprehensively integrate physiological signals, providing a more holistic understanding. In essence, our findings offer actionable insights for tailoring stress management techniques in integrating automated agents, aligning with the works of Lazarus and Folkman (Lazarus and Folkman, 1984).

In response to the critical assessment of our initial approach to situating our research within the broader academic study, this section aims to establish a direct and rigorous comparison between our findings and those of preceding studies. Our investigation focuses on understanding the dynamics between automated agents, stress, and individual performance under time pressure, with a particular emphasis on understanding the role of fast and slow automated agents in time-pressure scenarios involving both human and automated agents. Table 4.5 Presents a summary of previous studies that examine the impact of stress on performance, offering a direct comparison with our findings.

4.6 Summary

The findings from the lab-based experiment contribute to understanding the complex dynamics between automated agents, stress, and individual performance, particularly in time-pressure environments. In high-stress conditions, individuals working with automated agents adopted a narrower focus on immediate concerns, impacting decision-making and overall performance across different ability levels. The study assessed the impact of time pressure and agent speed on a block-removal task. Surprisingly, increased time pressure generally improved performance, with participants efficiently removing blocks. Workload assessments showed moderate mental and low physical demands, with individual differences in perceived workload. Notably, the study found varying effects of agent speed on performance. Participants adapted significantly with slow agents in high-pressure phases but showed no improvement with fast agents, suggesting a hindrance to strategic adaptation. Performance outcomes varied based on agent speed and competence, creating a competitive environment that affected overall performance. The research also highlighted the influence of time pressure and auditory distraction. Time pressure positively impacted performance, possibly due to increased motivation and focus. This study emphasized the intricate relationship between automated agents, stress, and performance. It recommended future research exploring physiological signals and considering individual differences to understand this complex dynamic comprehensively.

Chapter 5

Real-Life Applications and Usability of Research Findings

In the previous two chapters, we discussed the study design and results for individual and team performance. In this chapter, we transit from the theoretical exploration of the Impact of induced stress on individual performance, team Coordination, and Human-automated agent collaboration. We translate these insights into tangible applications across critical real-world contexts, how the designed tasks and result findings are not merely academic exercises but vital tools for enhancing operational efficiency and safety in sectors where the stakes are exceptionally high.

5.1 Real World Scenarios

The importance and applicability of the tasks that have been developed extend well beyond mere theoretical constructs, playing a pivotal role in addressing practical challenges encountered in diverse real-world situations. These tasks have been designed to cater to the complexities of scenarios where individual performance and seamless team coordination under stressful conditions are essential. Examples of such critical contexts include medical emergencies, where decisions under pressure with the right team coordination can be life-saving; air traffic control, where precision and efficiency are paramount for ensuring the safety of flights; and multi-drone management systems, where the arranging of multiple autonomous vehicles demands a high level of coordination. By exploring usability, this section discusses the immediate impact and practical applicability of the research findings, shedding light on how these tasks can be utilized or improved to understand human behaviour under high-pressure real-life situations, enhancing overall performance and streamlining complex operations.

1. **Air Traffic Control (ATC):** A complex domain where precision, quick decision-making, and team coordination are essential for managing aircraft movements safely and efficiently (Langan-Fox et al., 2009).

2. **Emergency Medical Response:** A high-stakes environment where medical teams must perform under stress to provide care and make life-saving decisions rapidly (Xiao et al., 2004).

3. **Multi-Drone Management for Disaster Relief:** An emerging field where coordination of autonomous systems can enhance disaster response efforts, requiring effective human-automation collaboration (Cummings et al., 2007).

5.2 Utility of Designed Tasks and Findings

The research findings shed light on several key areas: the effect of induced stress on individual and team performance, the critical role of team coordination strategies in high-pressure situations, and the significant potential for automated agents to enhance human performance. These insights offer a comprehensive framework for applying theoretical knowledge to practical challenges in critical operational environments.

5.2.1 Individual and Team Performance Under Stress

The findings from our study on the effects of induced stress on individual and team performance are relevant for training programs within air traffic control and emergency medical response sectors. Our investigation, focused solely on the impact of time pressure on performance, yielded promising outcomes for enhancing the performance of individuals and teams (Driskell et al., 1999). These insights apply to simulation-based training methods, equipping personnel to sustain high-performance levels across different stress conditions. This innovative approach involves a thorough understanding of the unique demands placed on individuals and teams in high-pressure situations. By dissecting these requirements and implementing strategic modifications to the fundamental structure of tasks, the Task becomes a valuable tool for gaining insights into employees' behaviours within high-pressure environments. This real-world application of the Task is critical to optimising task assignment and resource allocation in dynamic, high-pressure settings. Observing and analysing how individuals and teams respond under stress enables organisations to tailor their recruitment processes effectively. This, in turn, ensures that the right individuals are selected for roles requiring quick decision-making, effective team performance, and resilience in high-pressure scenarios.

5.2.2 Team Coordination Under Stress

Insights into implicit coordination and anticipation ratios resulting from the experimental analysis are especially relevant for medical teams in emergency medical response scenarios, where nonverbal cues and anticipatory actions can significantly save critical time and enhance patient outcomes. Similarly, in disaster relief operations, the principles of effective team coordination prove invaluable when applied to multi-agency teams tasked with responding to crises. These principles foster improved communication and collaboration between human responders and automated systems, streamlining efforts and maximizing the efficiency of disaster response initiatives (Xiao et al., 2004).

5.2.3 Human-Automation Collaboration

In air traffic control (ATC), the deployment of fast-response automated agents presents a significant advancement in supporting controllers by handling routine tasks or offering decision support during peak stress, thereby enhancing both safety and operational efficiency. This concept of automation extends into the management of multi-drone operations, where the beneficial effects of automated agents on performance highlight the potential for drones to autonomously carry out specific tasks under the supervision of operators (Parasuraman and Riley, 1997). Such an approach allows for a more effective distribution of human attention and resources, particularly in the context of disaster relief efforts. The integration of automation in these areas not only streamlines processes but also ensures a higher level of precision and responsiveness in critical situations, demonstrating the pivotal role of technology in augmenting human capabilities in high-stakes environments (Kaber and Endsley, 2004).

5.3 Application of Research Findings

The application of research findings across various fields showcases the potential of tailored technological solutions to enhance operational efficiency and effectiveness. In air traffic control (ATC), the implementation of adaptive automation systems that offer decision support by assessing real-time stress levels and workload of controllers can significantly improve safety and performance. Similarly, in the emergency medical response arena, the development of team training modules focused on supporting nonverbal communication and anticipatory skills is vital for navigating high-pressure medical emergencies effectively. Moreover, the field of multi-drone management benefits from creating drone control interfaces designed to adapt to the operator's stress levels, facilitating a more efficient distribution of tasks between human operators and drones during disaster relief operations. These advancements underscore the critical role of integrating research insights into practical applications, ensuring that teams across different sectors are equipped with the tools and skills necessary to manage demanding situations with greater competence and agility(Endsley, 2015).

5.4 Summary

The application of our research findings across air traffic control, emergency medical response, and multi-drone management for disaster relief represents the broad impact of understanding stress, team dynamics, and automation on improving performance in high-stakes environments. By bridging the gap between theoretical insights and practical applications, this research contributes to developing targeted interventions, training programs, and technologies. These advancements aim to enhance human performance, ensure safety, and optimize operational efficiency across various critical sectors, ultimately leading to more effective responses in emergencies and complex operational settings.

Chapter 6

Conclusion

We applied the groundwork in our literature review, investigating into stress measurement techniques, induction tests, and the role of automated agents. Shifting to empirical studies, we observed the tangible effects of induced stress on individual and team dynamics, uncovering the impact of time pressure and coordination strategies. Rigorous experiments unravelled intricate dynamics with automated agents, shaping cognitive strategies and decision-making. This chapter encompassed limitations, discussions, and future work and concluded with overarching remarks.

6.1 Limitations

While this research has made significant contributions to understanding the impact of induced stress and automated agents on individual and team performance, several limitations should be acknowledged, providing context for the interpretation of the findings. The study involved a total of 64 participants, with a mix of working professionals and students. The limited sample size and specific demographic composition may restrict the generalizability of the findings to broader populations. Future research with larger and more diverse samples could enhance the external validity of the results. Two of the three experimental studies were conducted online due to the evolving COVID-19 situation. While online experiments provided valuable insights, potential differences in participant engagement, task understanding, and stress perception in remote settings compared to in-person scenarios should be considered. The tasks designed for stress induction and team coordination, while carefully crafted to simulate real-world scenarios, may have limited generalizability to all high-pressure environments. The specificity of the tasks may influence the transferability of the results to different contexts. The experiment involving automated agents focused on their impact on individual performance. However, the nuanced dynamics of human-agent interaction may vary across different tasks and contexts. The study's findings should be interpreted within the context of the specific block-removal task used. The time constraints imposed on the experiments may not fully capture the long-term effects of stress on performance and coordination. Understanding how stress and coordination strategies evolve over extended periods could provide a more comprehensive picture. The ongoing COVID-19 situation influenced the choice of online experiments and may have introduced unforeseen variables that could impact participant stress levels and task performance.

6.2 Discussion

In this concluding chapter, we reiterate and organize the critical contributions of this thesis, emphasizing the main findings that advance our understanding of the intricate dynamics between stress, individual and team performance, and human-automation collaboration. To enhance clarity, we outline the main contributions in bullet points:

Literature Review and Theoretical Foundation:

- Conducted an in-depth literature review establishing the theoretical foundation.
- Explored stress measurement techniques, stress induction tests, and their effects on cognitive abilities and team coordination.
- Emphasized the pivotal role of automated agents in high-pressure scenarios, laying the groundwork for empirical investigations.

Empirical Studies on Stress Impact:

- Investigated the concrete impact of induced stress on individuals and teams.
- Explored the influence of time pressure on performance and the coordination strategies employed by teams under stress.
- Examined communication patterns and anticipation ratios, providing valuable insights into enhancing performance in high-pressure challenges.

Influence of Automated Agents:

- Explored the influence of automated agents on individual performance under stress through rigorous experimental studies.
- Unraveled the complex dynamics, revealing significant impacts on cognitive strategies, decision-making processes, and overall performance.

- Highlighted the pivotal factors of time pressure, auditory distractions, and competition with automated agents shaping performance outcomes.

Practical Implications:

- Furnished actionable strategies derived from empirical studies for domains facing frequent high-pressure conditions.
- Offered practical interventions to improve individual and team performance in demanding, stressful environments.

Theoretical Advancement and Interdisciplinary Insights:

- Contributed to a comprehensive body of research, advancing theoretical understanding.
- Highlighted the delicate nature of human performance under stress, emphasizing the imperative need for holistic research to navigate critical challenges effectively.

The discussion section investigates understanding individual performance, team performance, team coordination, and human-automated agent collaboration under induced stress. Key insights include the observation that mild stress, induced by time pressure, can improve individual performance while negatively impacting team performance in collaborative settings. Coordination strategies emphasizing implicit coordination and a high anticipation ratio emerged as crucial elements for effective teamwork under stress. Additionally, the investigation into the influence of automated agents revealed their significant impact on participants' performance. The presence of slow agents led to slower overall performance, whereas competition against fast agents resulted in improved performance. These findings provide valuable insights into integrating automated agents into human workflows, particularly in high-stress situations.

6.3 Future Work

In acknowledging the limitations of this research, we recognize the need for future exploration. This includes investigating additional stressors, developing interventions to enhance team performance under stress, and exploring advanced automated technologies for improved human-automation collaboration. Pursuing these avenues can further enhance our understanding of human performance in high-stress environments and contribute to designing effective systems and interventions to support individuals and teams in such contexts.

- **Explore Diverse Stressors:**Investigate cognitive load, environmental factors, and emotional stress to understand their impact on individual and team performance, coordination, and human-automation collaboration.
- **Develop Interventions:** Focus on creating strategies and interventions, such as mindfulness training and team-building exercises, to mitigate the adverse effects of stress on team performance. Leverage Technology for Stress Reduction:
- **Leverage Technology for Stress Reduction:** Explore the role of technology in supporting stress reduction and team collaboration, aiming to design novel tools and interfaces for stress management and optimized coordination.
- **Examine Long-Term Effects of Stress:** Shift focus to studying the long-term effects of stress on individuals and teams, providing insights into chronic stress exposure and strategies for stress resilience and recovery.
- **Integrate Advanced Automation Technologies:** Investigate how advanced automation systems can seamlessly integrate into human workflows, adapt to stress levels, provide real-time feedback, and automate tasks for improved human automation collaboration in high-stress scenarios.

These integrated future research directions aim to advance the understanding of stress dynamics, develop effective interventions, and leverage technology to enhance performance and coordination in high-stress environments.

6.4 Concluding Remarks

In conclusion, this thesis contributes to understanding the intricate dynamics between stress, individual and team performance, and human-automation collaboration. Through an in-depth literature review, we established a theoretical foundation, emphasizing the role of automated agents. Empirical studies unveiled concrete impacts of induced stress, shedding light on time pressure’s dual effect on individual and team performance. Our exploration of automated agents’ influence revealed complex dynamics shaping cognitive strategies and decision-making. Practical implications provide actionable strategies for high-pressure domains. Theoretical advancement underscores the delicate nature of human performance under stress. The discussion section highlights vital insights, including the observed effects of mild stress on individual performance and its contrasting impact on team collaboration. Acknowledging limitations, future work is proposed to explore diverse stressors, develop interventions, leverage technology for stress reduction, examine long-term effects, and integrate advanced automation technologies. These integrated efforts aim to advance understanding of stress dynamics, develop effective interventions, and leverage technology for enhanced performance and coordination in high-stress environments.

Appendix A

Remaining Time Series Plot's and Transcription

This chapter presents the remaining plots from the tasks assessing individual expertise and team coordination.

A.1 Individual Expertise Measurement Task

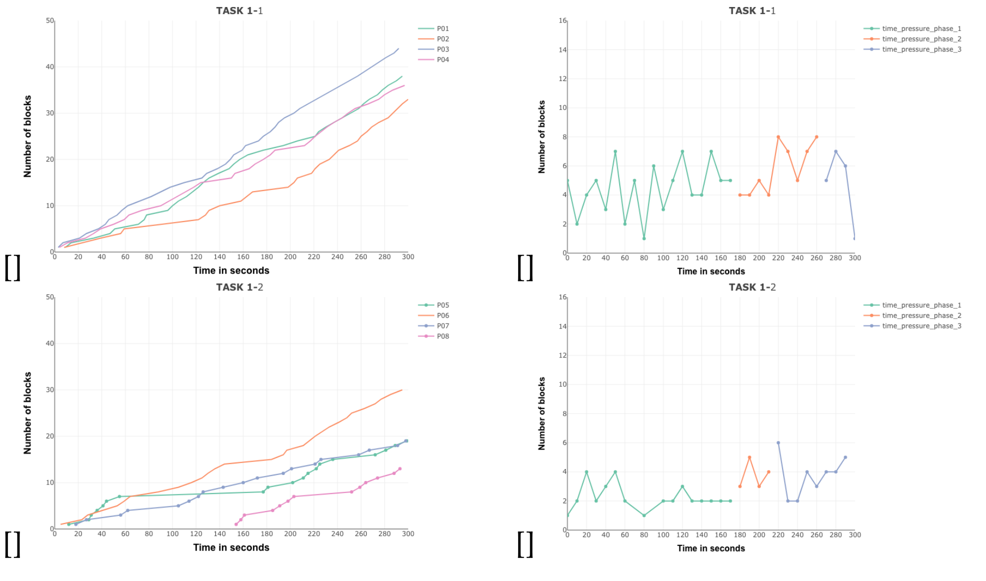

FIGURE A.1: Time series plot for Task 1 :**(a)** Group 1 Time Plot; **(b)** Group 1 Time pressure impact; **(c)** Group 2 Time Plot; **(d)** Group 2 Time pressure impact

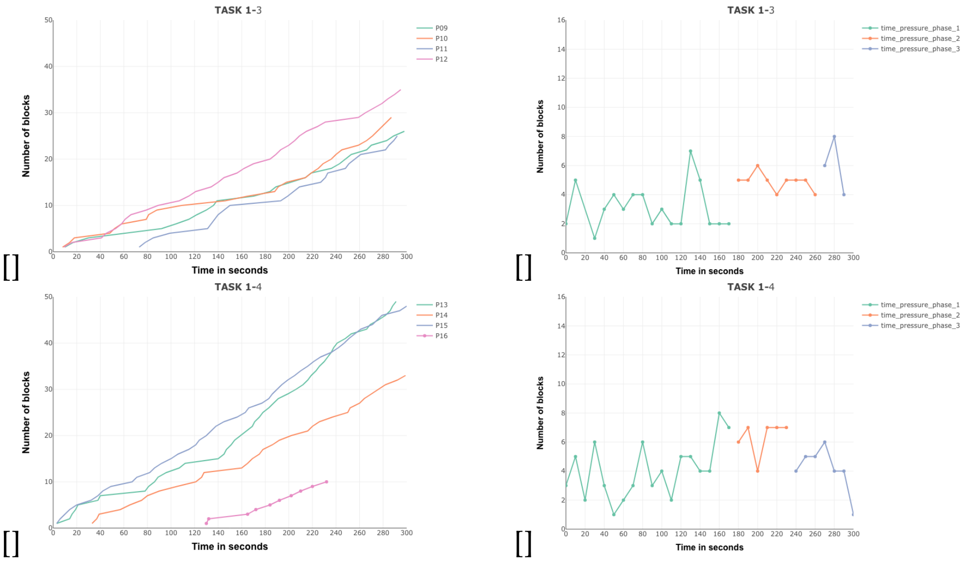

FIGURE A.2: Time series plot for Task 1 :; **(E)** Group 3 Time Plot; **(f)** Group 3 Time pressure impact; **(g)** Group 4 Time Plot; **(h)** Group 4 Time pressure impact

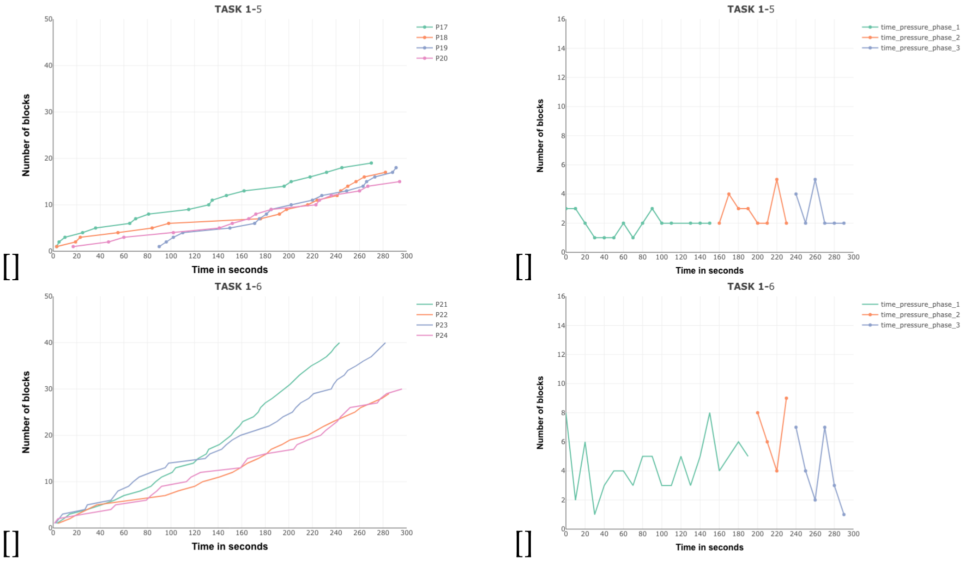

FIGURE A.3: Time series plot for Task 1 :**(a)** Group 4 Time Plot; **(b)** Group 4 Time pressure impact; **(c)** Group 5 Time Plot; **(d)** Group 5 Time pressure impact

A.2 Team Coordination Task

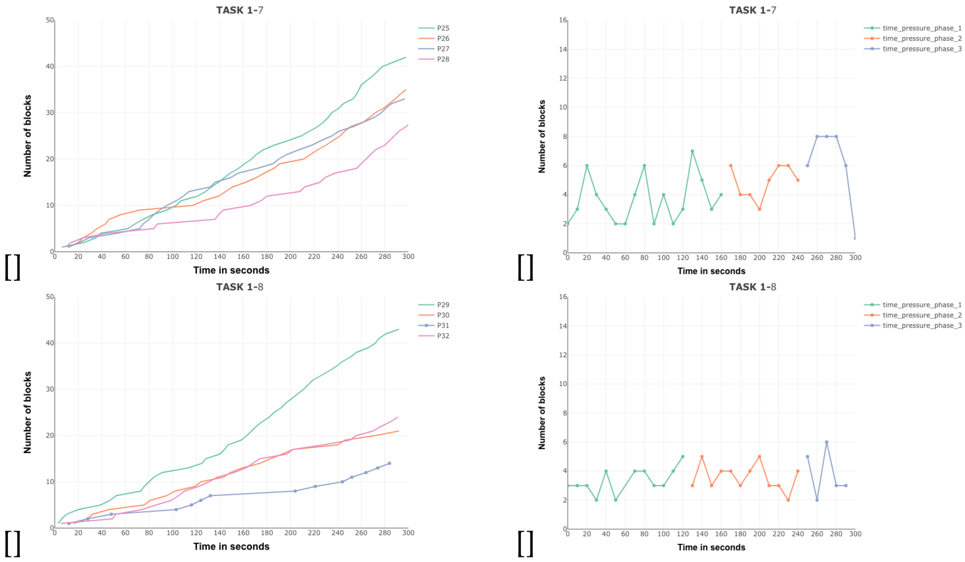

FIGURE A.4: Time series plot for Task 1 :; **(E)** Group 6 Time Plot; **(f)** Group 6 Time pressure impact; **(g)** Group 7 Time Plot; **(h)** Group 8 Time pressure impact

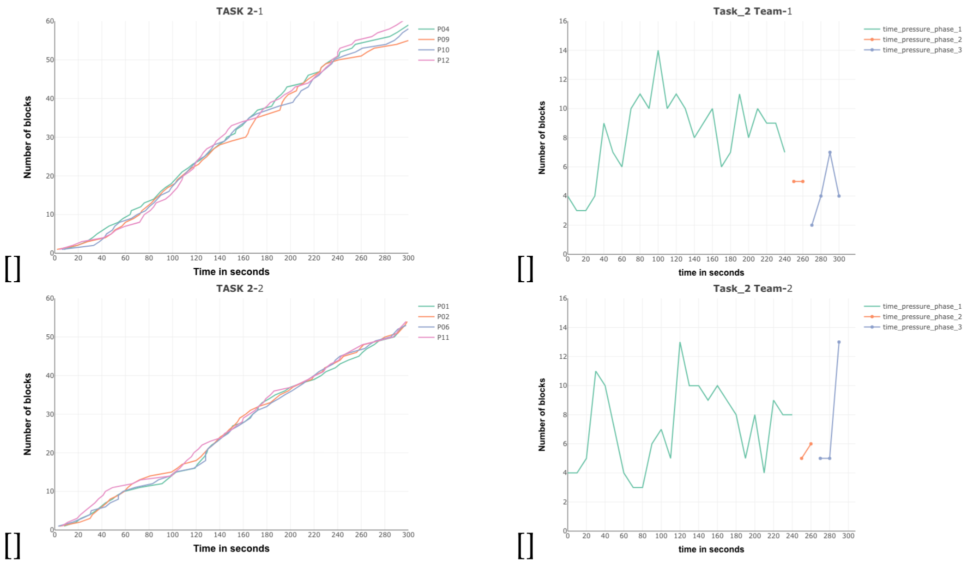

FIGURE A.5: Time series plot for Task 1 :**(a)** Group 4 Time Plot; **(b)** Group 4 Time pressure impact; **(c)** Group 5 Time Plot; **(d)** Group 5 Time pressure impact

A.3 Total Experiment Summary

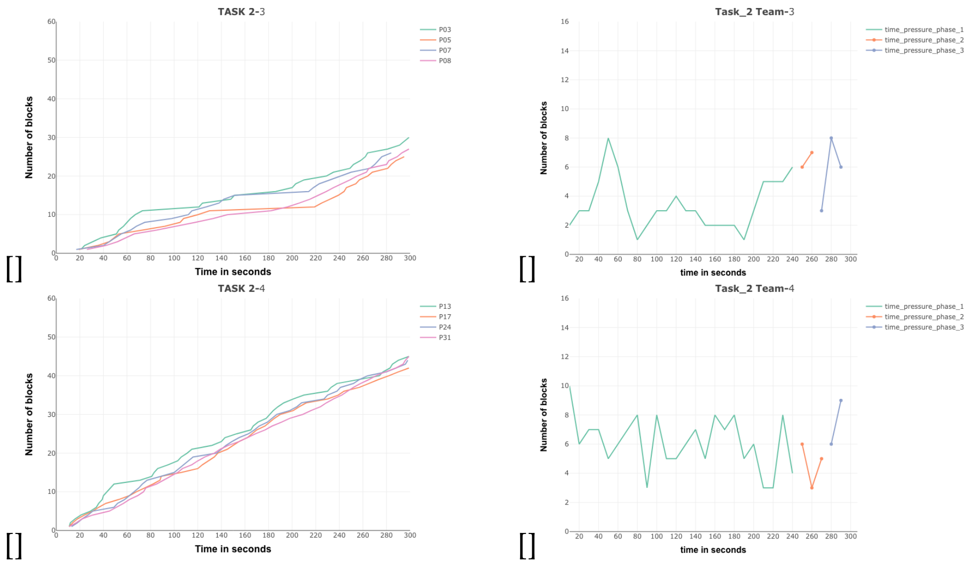

FIGURE A.6: Time series plot for Task 2 :**(a)** Team 1 Time Plot; **(b)** Team 1 Time pressure impact; **(c)** Team 2 Time Plot; **(d)** Team 2 Time pressure impact

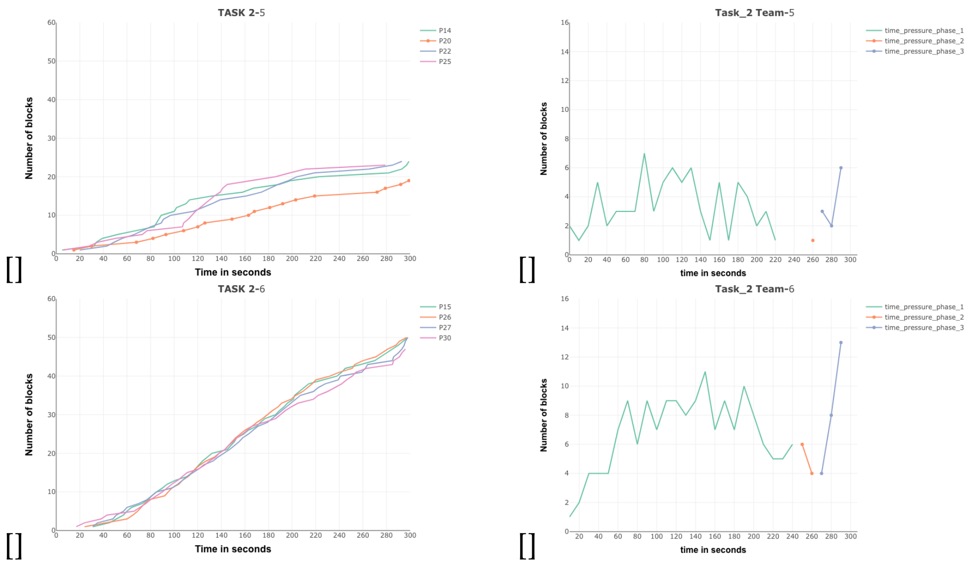

FIGURE A.7: Time series plot for Task 2 : Time series plot for Task 2 :**(a)** Team 5 Time Plot; **(b)** Team 5 Time pressure impact; **(c)** Team 6 Time Plot; **(d)** Team 6 Time pressure impact

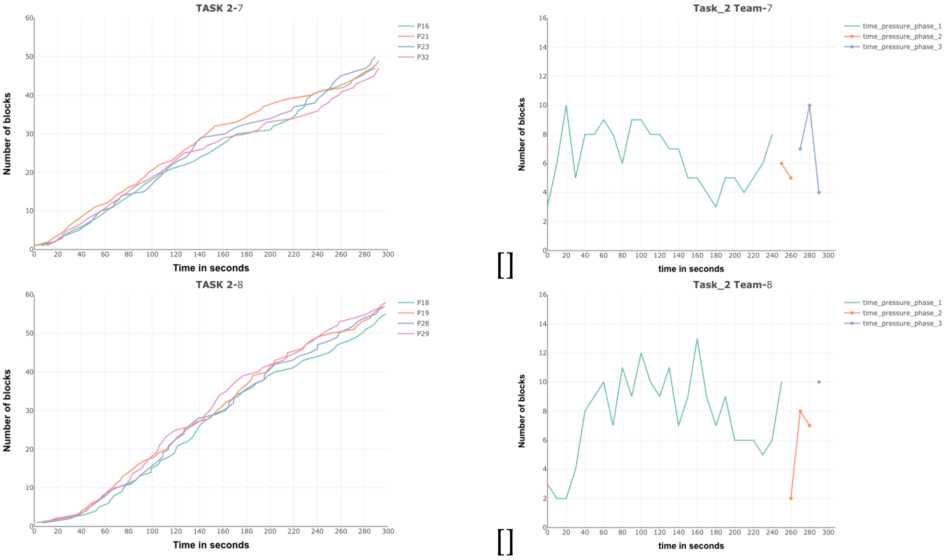

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FIGURE A.8: Time series plot for Task 2 : **(E)** Team 7 Time Plot; **(f)** Team 7 Time pressure impact; **(g)** Team 8 Time Plot; **(h)** Team 8 Time pressure impact

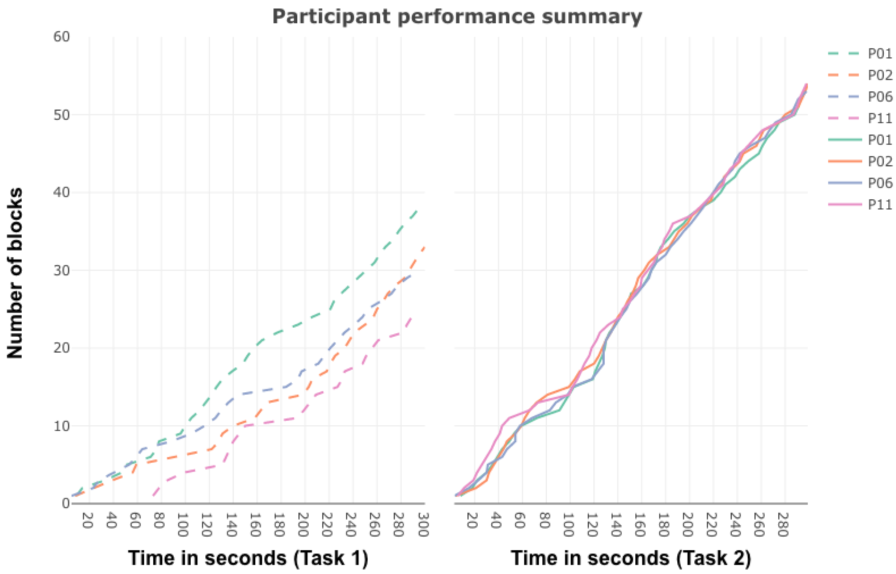

FIGURE A.9: Time series plot for team 2

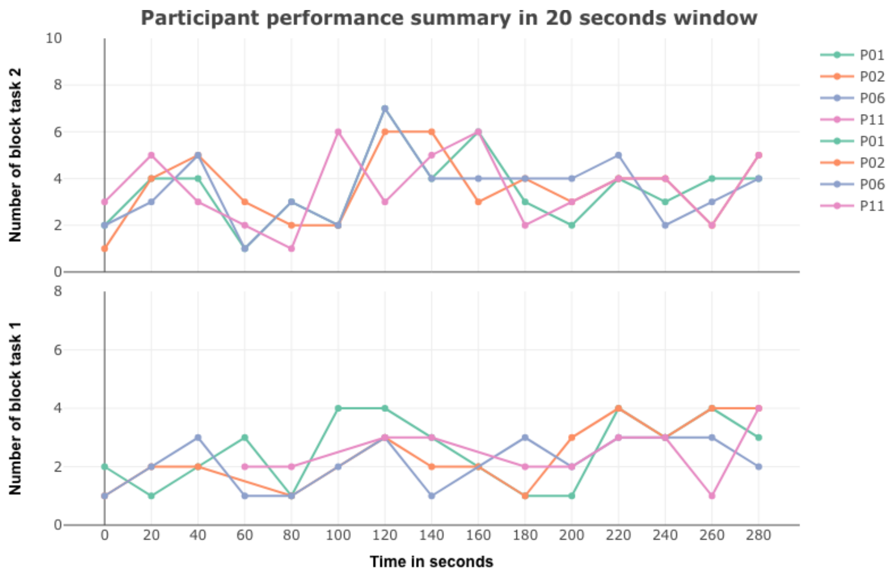

FIGURE A.10: Windowed time series plot for team 2

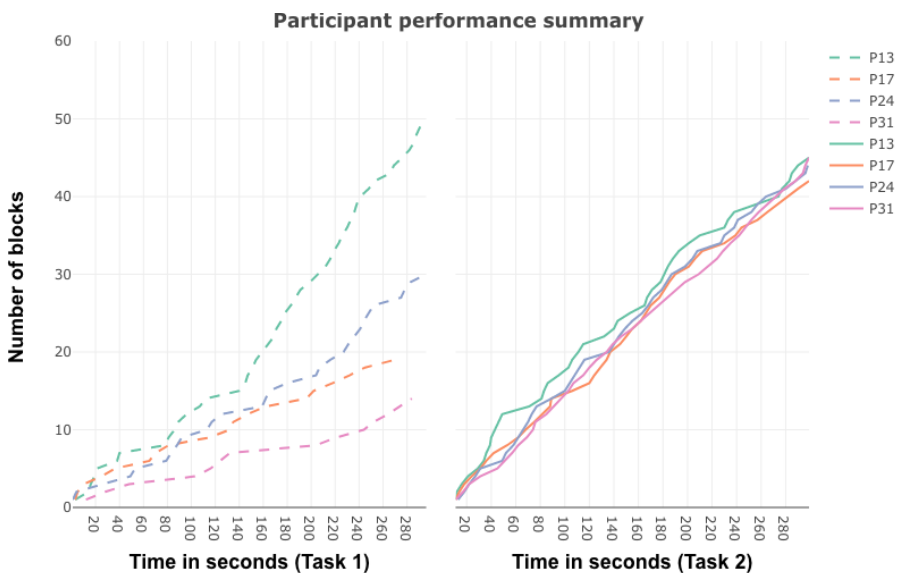

FIGURE A.11: Time series plot for team 4

TABLE A.1: Transcription of second team audio communication converted into text.

Ch.	Transcribe	Events
1	.....	
2	.....	
3	.....	
4	.....	
5	.....	
6	.....	
7	Laughing	
8	**(P11):** H1 Needs to go	
9	**(P11):** Than the others	
10	**(P11):** Red gray	
11	.....	
12	.....	
13	.....	
14	.....	
15	.....	
16	.....	
17	.....	
18	.....	
19	.....	**(Researcher):** You can only remover one block at a time
20	.....	
21	.....	
22	**(P01):** Thank you **(P01):** G18 Please	
23	**(P01):** G19 okay I am the G19 Laughing,**(P02):** B23 please, gray yeah sorry	
24	**(P02):** I cant, A23,**(P01):** No	**(Researcher):** One minute left
25	**(P06):** H19 red,**(P11):** Just one second	
26	**(P01):** Gray B23 **(P02):** Yeah I know but I can't there is A23 or can I? , **(P01):** No No You can	
27	**(P02):** Okay Okay, I am not sure **(P01):** Laughing	**(Researcher):** 30 second
28	**(P09):** Ahh sorry	**(Researcher):** 20 second
29	**(P11):** Whee	
30	.....	**(Researcher):** 5 second, 4, 3, 2, 1, Stop

TABLE A.2: Transcription of third team audio communication converted into text.

Sec	Transcribe	Events
20	**(P05):**ohh f***, What the f***, Sorry, **(P05):** f***, f**** sliva	
40	**(P05):** go (P03) go,	
60	....	....
80	Laughing, **(P07):** Remove the green one from E column	
100	**(P05):** Common P08, **(P07):** Yes i am waiting, **(P08):**, I stop it	
120	**(P03):** They are removing already	**(Researcher):** You can ask team member to remove their blocks
140	**(P05):** Common team 3 we can do it we are in it for money, **(P05):** There is green on 10 P08, **(P08):** Yeah I have remove it	
160	**(P08):** I removed it now	
180	**(P03):** P08 there are green on tops mostly, **(P08):** Yeah, but gray didn't removed his, **(P07):** There is no turn remove as much as from your colour, **(P05):** go p08 go, **(P08):** laughing	
200	**(P05):** and again, p08 keep going remove all	**(Researcher):** You can only remover one block at a time
220	**(P05):** go P08, go Po8 I cant, try to remove all of them from all column please	
240	nice nice, **(P02):**	**(Researcher):** One minute left
260	**(P03):** How do i know if you are cheating	
280	**(P05):** go go go	**(Researcher):** 30 second left
300	**(P10):** a17 please I can get two yellow from it, **(P07):** On the a column yes	**(Researcher):** 5 second, 4, 3, 2, 1, Stop

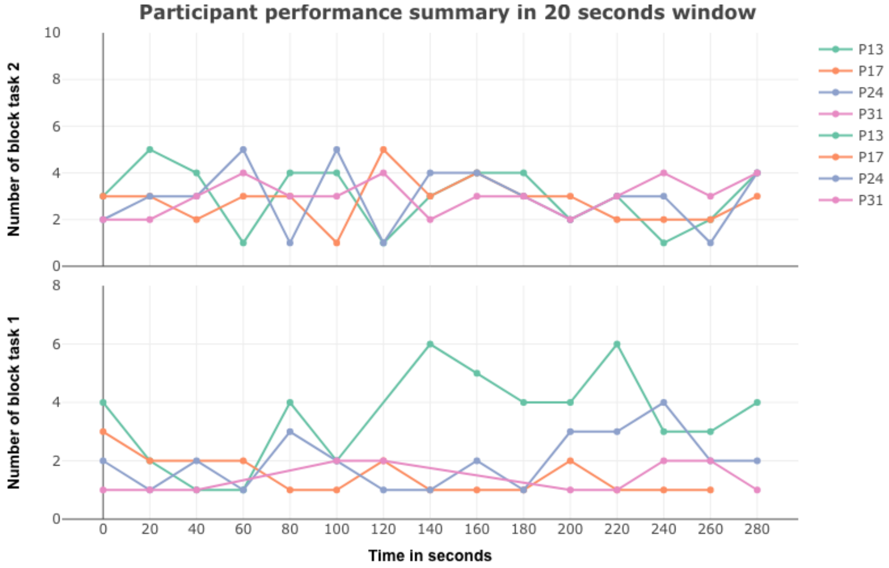

FIGURE A.12: Windowed time series plot for team 4

TABLE A.3: Transcription of fourth team audio communication converted into text.

Sec	Transcribe	Events
20	....	
40	**(P24):** Please remove red E2, E2	
60	**(P24):** E2	
80	**(P13):** Could you remove A if possible, Thanks **(P24):** Please	
100	**(P24):** A9 red A9, **(P17):** Can somebody remove from H, H Red, Red please	
120	**(P17):** Green from H	
140	P green, C A10, **(P24):** Red C10, Red C10, Red C10 Thanks	
160	**(P17):** H red please	
180	**(P13):** Green if you got chance it would be appreciated, **(P17):** Cheers	**(Researcher):** 2 minute 30 second left
200	....	
220	**(P17):** H Green please, H green ok ok sorry	
240	**(P17):** H red please, **(P17):** Yellow D yes	
260	....	**(Researcher):** one minute left
280	**(P13):** Thank you, Could you do C if possible, **(P24):** F gray please, F gray	**(Researcher):** 30 second left
300	**(P17):** Scroll problem is coming,**(P31):** please	**(Researcher):** 9,8,7,6,5,4,3,2,1 Stop

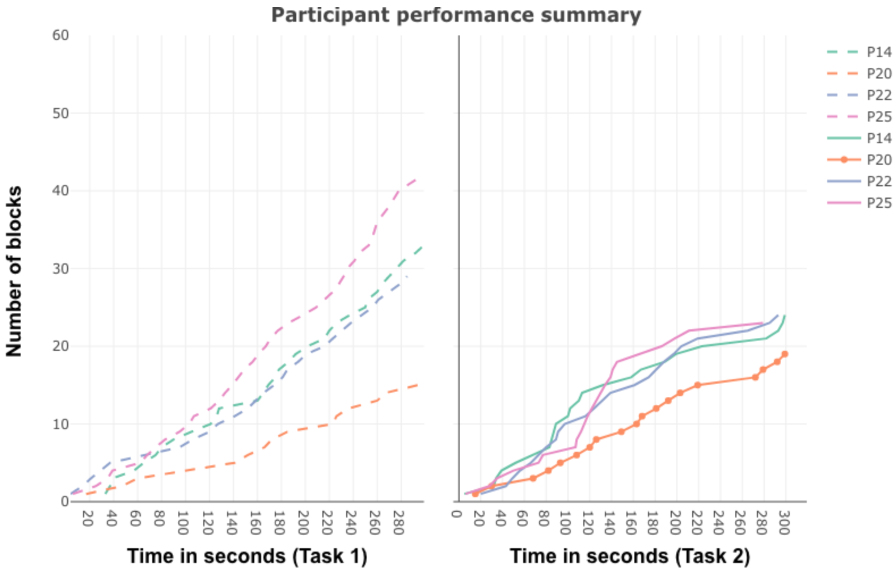

FIGURE A.13: Time series plot for team 5

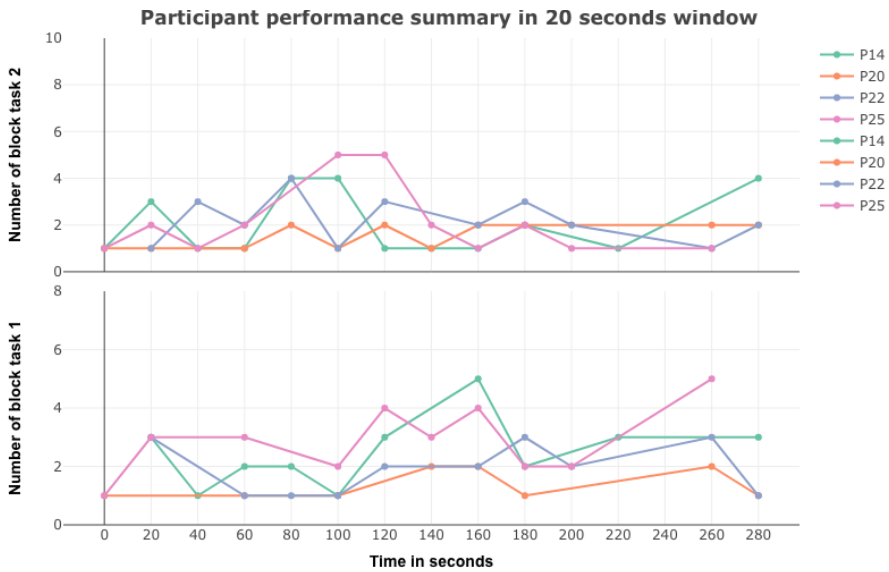

FIGURE A.14: Windowed time series plot for team 5

TABLE A.4: Transcription of fifth team audio communication converted into text.

Sec	Transcribe	Events
20	**(P22):** P25 Remove yellow, D gray P25, **(P20):** Ok, **(P22):** I am removing mine, **(P22):** Remove P24 its your turn	**(Researcher):** You can remove you don't need to wait for other people
40	**(P14):** Yellow so you can go, **(P22):** P25 you need to remove C yellow, P14 C red, thanks	
60	**(P14):** green and grays, **(P22):** P14 C red, Thanks	
80	**(P20):** Who is D, **(P20):** P22 Remove D, **(P22):** Let	
100	**(P14):** E green will be useful, Thanks, **(P22):** A gray remove a gray	
120	**(P20):** Removed, green please, P22 your turn	
140	**(P14):** gray is , frequently quite a lot, **(P20):** Yes, like my system is lagging a lot so i cant correct, **(P22):** P25 remove a yellow please	
160	**(P22):** D D red remove red	
180	....	
200	**(P22):** system is little slow	**(Researcher):** one minute 30 second left
220	**(P22):** We all blocked up, **(P20):** Yes I cant paste it i don't know why its not pasting for me, **(P22):** Remove g	
240	**(P22):** Remove H, I think P20 having some problem, **(P20):** Yes my system legging when ever paste it it not reach there and doesn't load the sheet again	
260	**(P22):** Network Problem, **(P20):** I am trying but nothing is getting pasted, start	
280	**(P22):** Researcher P20 is having problem	**(Researcher):** YEs I can see, Dont worry I will see later. 30 second later
300	**(P22):** B should be there, two or red are open	**(Researcher):** 5,4 ,3,2,1 stop

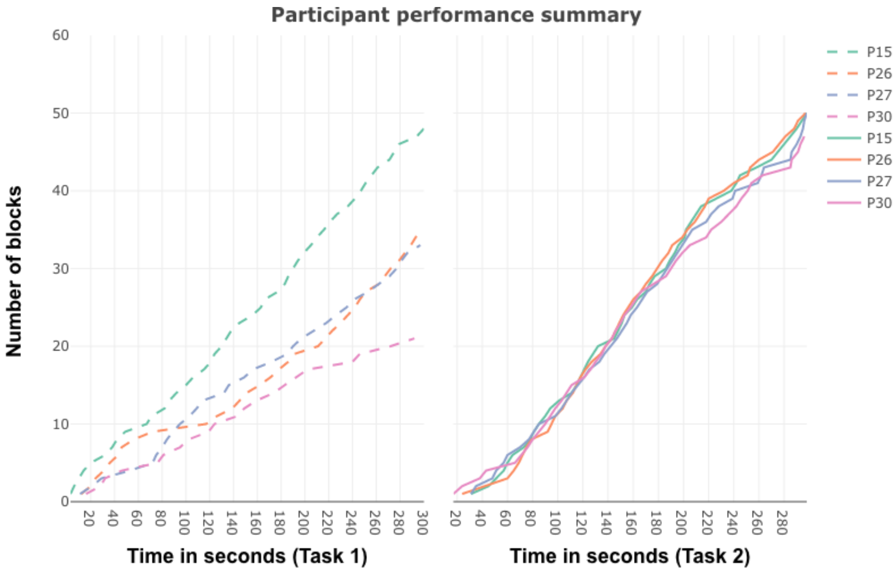

FIGURE A.15: Time series plot for team 6

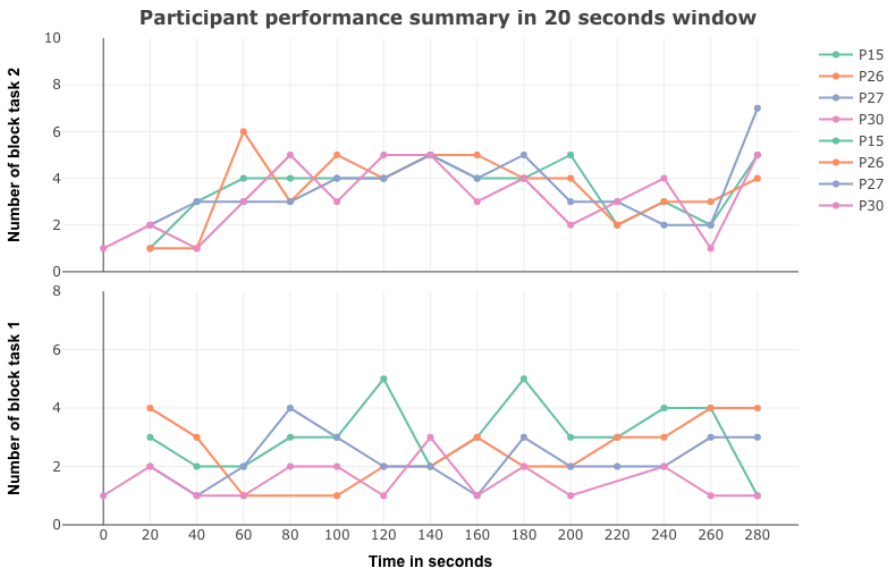

FIGURE A.16: Windowed time series plot for team 6

TABLE A.5: Transcription of sixth team audio communication converted into text.

Sec	Transcribe	Events
20	**(P26):** Red A, Its your turn, **(P27):** I can see actually, I am not red I can see	
40	**(P30):** D3, **(P6):** Red C	
60	**(P26):** A yellow, **(P30):** Can we remove others block **(P27):**. H gray, thanks	**(Researcher):** No, you can not you can only remove your block
80	**(P30):** A gray, **(P26):** A yellow	
100	**(P27):** H, A red, **(P30):**G gray, Thanks	
120	**(P30):** B green, **(P27):** A, A gray	
140	**(P15):** A green	
160	, **(P26):** Yellow a, **(P15):** Yes	**(Researcher):** You have 2 minute 30 second left
180	**(P30):** A green, Thanks**(P26): Yellow a**	
200	**(P15):** B gray	
220	**(P15):** C red	**(Researcher):** one minute 30 second left
240	**(P27):** A B red, **(P15):** H red	**(Researcher):** 1 minute left
260	**(P26):** H B red Please	
280	**(P15):** D gray **(P30):** D gray	**(Researcher):** 30 second left
300		**(Researcher):** 10 second 9,8,7,6,5,4,3,2,1 Stop

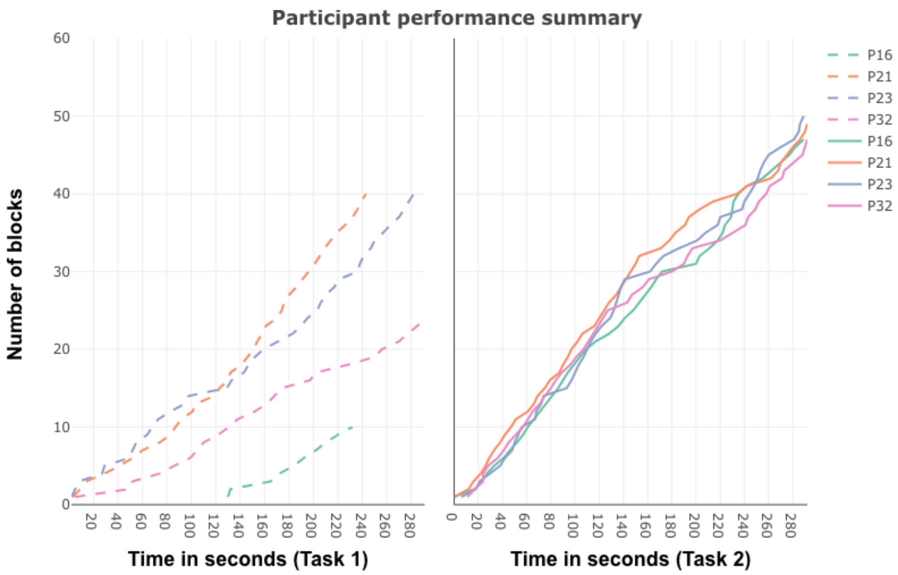

FIGURE A.17: Time series plot for team 7

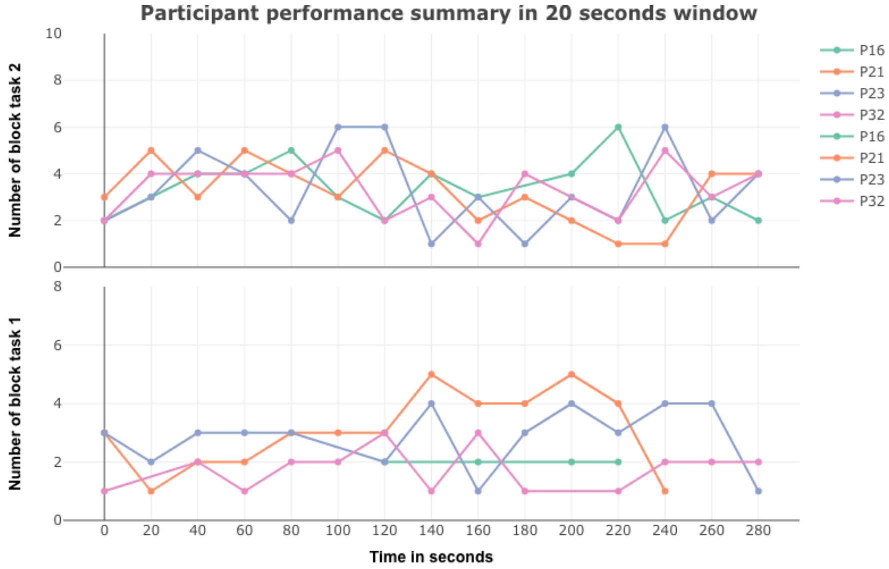

FIGURE A.18: Windowed time series plot for team 7

TABLE A.6: Transcription of seventh team audio communication converted into text.

Sec	Transcribe	Events
20	....	
40	....	
60	...	
80	Singing	
100	**(P21):** Remove red, **(P23):** Third red	
120	**(P21):** Thank you, **(P23):** Red h red	
140	**(P23):** H red, F red **(P21):**, A green , **(P16):** Remove H	
160	**(P21):** B red, **(P23):** G green	**(Researcher):** 2 minute 30 second left
180	**(P21):** B red, **(P23):** G green	
200	**(P21):** G gray, A red, A red, **(P23):** H red	
220	**(P21):** F red, D, **(P23):** F red , D yellow	**(Researcher):** One minute 30 second left
240	**(P21):** A red, H G H red, **(P23):** H red, H rd	
260	**(P23):** So many red, Is she allow to take all red at same time, There is a lot, **(P16):**(....)	**(Researcher):**One minute, No
280		
300	**(P23):** G green	**(Researcher):** 10,9,8,7,6,5,4,3,2,1 Stop

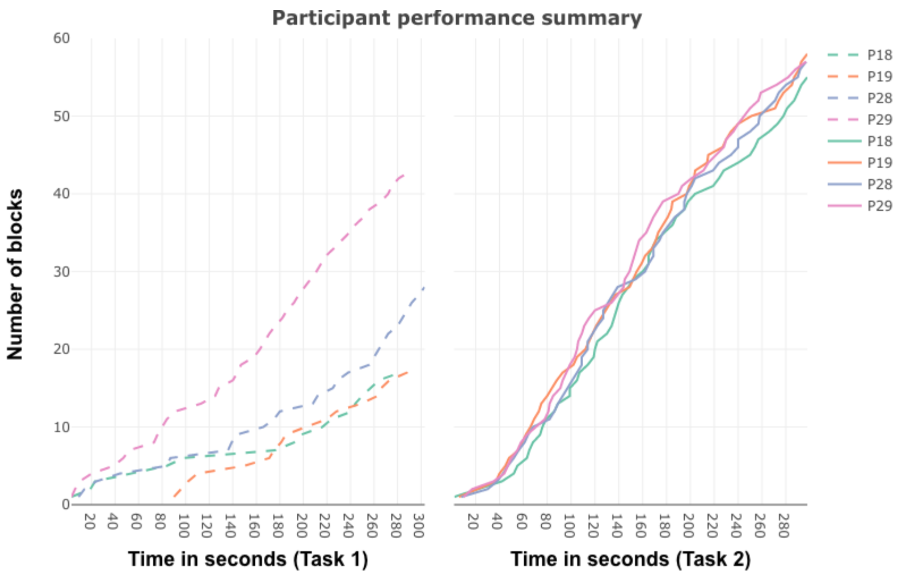

FIGURE A.19: Time series plot for team 8

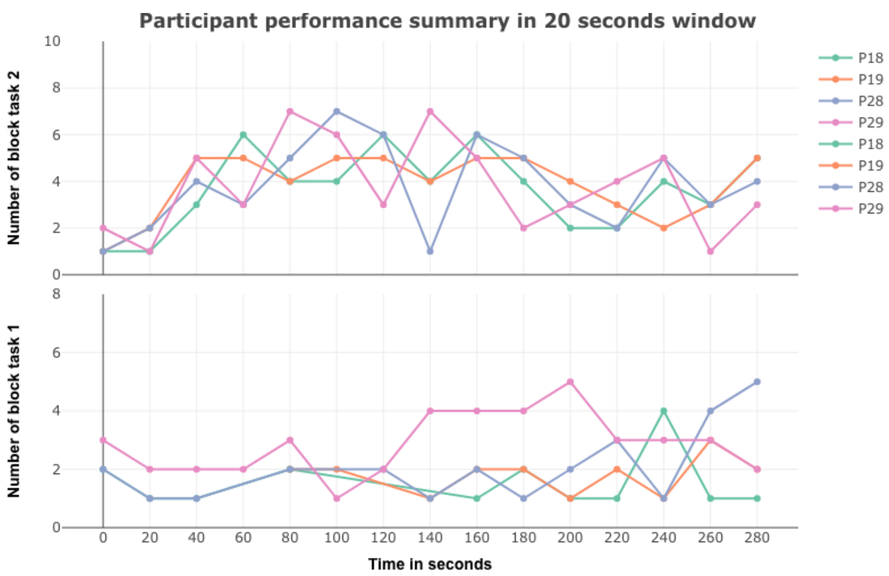

FIGURE A.20: Windowed time series plot for team 8

TABLE A.7: Transcription of eighth team audio communication converted into text.

Sec	Transcribe	Events
20	**(P18):** Next one	
40	**(P28):** Red red red, **(P18):** Next next next, yellow,**(P20):** Sinking issue	
60	**(P31):** There is red on A **(P128):** Everbody do it continuously, if somebody block you than speak	
80	**(P28):** Very Simple, **(P31):** There is one on H, ohh s***	
100	**(P18):** I understood game,**(P31):** I forget colour in middle **(P18):** No worries It happens **(P19):** Hey somebody removed from centre	
120	**(P18):** No worries, **(P19):** H red, **(P18):** Taking time there is sinking issue, **(P28):** Hmmm	
140	**(P19):** B red, **(P31):** waiting for green, G, **(P18):** Whenever i see my red I am removing it as soon as possible, Red D	
160	**(P128):** Guys I am blocked with yellow, **(P19):** B green, **(P18):** How much time left, sinking issue	**(Researcher):** half of the time
180	**(P19):** G yellow, Yellow	
200	**(P19):** G and H	**(Researcher):** You can only remove one block at a time
220	**(P28):** Even though they are stacked? Ok you didn't tell this	
240	**(P28):** Red Red, Fast bro, **(P19):** Its getting up and down too much,**(P28):** let red come	**(Researcher):** One minute left
260	**(P19):** Red yellow, **(P28):** This rows are very down and we are up	
280	**(P18):** There is issue, **(P31):** If you can remember C red **(P19):** G yellow, **(P18):** Issue with up down	
300	**(P18):** please tell us time, **(P19):** Seconds don't go fast **P28** Leave the time guys focus here	**(Researcher):** 10,9,8,7,6,5,3,2,1 Stop

Appendix B

Questionnaires and Google Forms

This chapter contains the questions from demography, questionnaire 1, questionnaire 2, perceived stress scale and NAS-TLX.

B.1 Demographic Questions

1. What gender do you identify as?
   A. Male
   B. Female
   C. ......(Answer)
   D. Prefer not to say.

2. What is your age?
   A. 0 - 15 years old
   B. 15 - 30 years old
   C. 30 - 45 years old
   D. 45+
   E. Prefer not to answer.

3. Please specify your ethnicity.
   A. Caucasian
   B. African-American.
   C. Latino or Hispanic
   D. Asian
   E. Native American.
   F. Native Hawaiian or Pacific Islander.
   G. Two or More
   H. Other/Unknown
   I. Prefer not to say.

4. What is the highest degree or level of education you have completed?
   A. Some High School
   B. High School
   C. Bachelor's Degree
   D. Master's Degree
   E. Ph.D. or higher
   F. Trade School
   G. Prefer not to say.

5. Are you married?
   A. Yes
   B. No
   C. Prefer not to say.

6. What is your current employment status??
   A. Employed Full-Time
   B. Employed Part-Time
   C. Seeking opportunities
   D. Retired
   E. Prefer not to say.

B.2 Procedure

1. Microsoft Teams was used to connect all of the participants and the researcher.

2. The researcher explained the task procedure to the participants.

3. Over the Microsoft Teams chat box, the researcher sent a demographic questionnaire and a perceived stress scale questionnaire based on a Google form.

4. The participants were divided into two groups at random by the researcher.

5. Participants were given a Google sheet-based task by the researcher, who instructed them not to open the sheet before beginning the task.

6. The researcher demonstrated how to complete the task using screen share with the participants.

7. The researcher assigned each participant a colour at random and set a time limit of 300 seconds.

8. The researcher instructed the participants to open their Google Sheet and begin the task as soon as the researcher permitted them to do so.

9. The task was recorded by the researcher using a UBS.

10. By informing the participants about the remaining time, the researcher was trying to divert their attention away from the task at hand.
11. The second team went through the same procedure.
12. Following the first task, a survey was circulated to all participants via Microsoft chat box.
13. All participants were divided into different-level teams based on the results of the first task and the Stress Scale test.
14. Each participant was given information about their teams but not about the members of their teams.
15. The researcher explained the second task's rules to the participants.
16. Participants were assigned a colour box and given 300 seconds to complete the task.
17. The researcher instructed the participants to open their Google Sheet and begin the task as soon as the researcher permitted them to do so.
18. By informing participants about the remaining time, the Researcher was trying to divert their attention away from the task at hand.
19. The second team went through the same procedure.
20. Following the second task, participants were given NASA-TLX and a questionnaire to complete.
21. The researcher expressed his gratitude to all of the participants and kept the video recording and collected data in a secure location.

B.3 Perceived Stress Scale

For each question choose from the following alternatives:
0 - never, 1 - almost never, 2 - sometimes, 3 - fairly often, 4 - very often

1. In the last month, how often have you been upset because of something that happened unexpectedly?
   Answer (..........)
2. In the last month, how often have you felt that you were unable to control the important things in your life?
   Answer (..........)

3. In the last month, how often have you felt nervous and stressed?
   Answer (..........)

4. In the last month, how often have you felt con dent about your ability to handle your personal problems?
   Answer (..........)

5. In the last month, how often have you felt that things were going your way?
   Answer (..........)

6. In the last month, how often have you found that you could not cope with all the things that you had to do?
   Answer (..........)

7. In the last month, how often have you been able to control irritations in your life?
   Answer (..........)

8. In the last month, how often have you felt that you were on top of things?
   Answer (..........)

9. In the last month, how often have you been angered because of things that happened that were outside of your control?
   Answer (..........)

10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?
    Answer (..........)

B.4 Questionnaire for Individual Performance

1. To what extent do you think that time pressure makes you stressful?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

2. To what extent do you become stressed while watching other participants' performances?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

3. To what extent do you think you didn't have enough time to get everything done?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

4. To what extent do you think you were having trouble in completing tasks in a given time?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

5. To what extent do you think this task makes you sensitive and irritable?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

6. To what extent do you think this task makes you stressed?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

7. Have you ever play or work in task similar to this?
   A. Yes
   B. No

8. If you think the proposed task doesn't make sense, would you please explain your reasons or comments?
   In your opinion, does the proposed user task make sense to you? If yes, please explain.

   ....
   ....
   ....
   ....
   ....
   ....
   ....

B.5 Questionnaire For Team Performance

1. To what extent do you feel time pressure makes you stressed?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

2. How successful do you believe you were in completing the task we assigned to you, and how satisfied were you with the results?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

3. to what extent you feel insecure. discouraged. irritated. and annoyed?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

4. To what extent do you feel stranger team members make you stressed and less confident in completing the tasks?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

5. To what extent do you feel task was easy?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

6. To what extent do you feel you were able to coordinate with team members?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

7. To what extent do you feel in your group other members are weak players?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

8. To what extent do you feel you can perform better in a laboratory-based environment?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

9. To what extent do you believe receiving a reward for a winning team will encourage you to complete a task properly?
   O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

10. To what extent do you feel comfortable in recording tasks?
    O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

11. How stressful do you find auditory distraction and researcher interference during a task?
    O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

12. To what extent do you feel the first experiment session helped you to complete the second experiment more efficiently?
    O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

13. To what extent do you believe that having an agent to support you in selecting the appropriate cell will benefit you in completing tasks more quickly?
    O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

14. To what extent do you believe that members of your team were weak players?
O Strongly disagree O Disagree O Neither agree nor disagree O Agree O Strongly agree.

15. What are your thoughts on the task's type?
A. Skill Based
B. Rule Based
C. Knowledge Based

B.6 NASA Task Load Index

Mental Demand

How mentally demanding was the task?

[y=.15cm, x=0.04 * font=] (0,0) – coordinate (x axis mid) (20,0);

in 0 (,0pt) – (,15pt) node[anchor=south] ;

in 1,...,9 (,0pt) – (,5pt) node[anchor=south] ;

in 10 (,0pt) – (,15pt) node[anchor=south] ;

in 11,...,19 (,0pt) – (,5pt) node[anchor=south] ;

in 20 (,0pt) – (,15pt) node[anchor=south] ;

Very Low Very High

Physical Demand

How physically demanding was the task?

[y=.15cm, x=0.04* font=] (0,0) – coordinate (x axis mid) (20,0);

in 0 (,0pt) – (,15pt) node[anchor=south] ;

in 1,...,9 (,0pt) – (,5pt) node[anchor=south] ;

in 10 (,0pt) – (,15pt) node[anchor=south] ;

in 11,...,19 (,0pt) – (,5pt) node[anchor=south] ;

in 20 (,0pt) – (,15pt) node[anchor=south] ;

Very Low Very High

Temporal Demand

How hurried or rushed was the pace of the task?

[y=.15cm, x=0.04* font=] (0,0) – coordinate (x axis mid) (20,0);

in 0 (,0pt) – (,15pt) node[anchor=south] ;

in 1,...,9 (,0pt) – (,5pt) node[anchor=south] ;

in 10 (,0pt) – (,15pt) node[anchor=south] ;

in 11,...,19 (,0pt) – (,5pt) node[anchor=south] ;

in 20 (,0pt) – (,15pt) node[anchor=south] ;

Very Low Very High

Performance

How successful were you in accomplishing what you were asked to do?

[y=.15cm, x=0.04* font=] (0,0) – coordinate (x axis mid) (20,0);

in 0 (,0pt) – (,15pt) node[anchor=south] ;

in 1,...,9 (,0pt) – (,5pt) node[anchor=south] ;

in 10 (,0pt) – (,15pt) node[anchor=south] ;

in 11,...,19 (,0pt) – (,5pt) node[anchor=south] ;

in 20 (,0pt) – (,15pt) node[anchor=south] ;

Very Low Very High

Effort

How hard did you have to work to accomplish your level of performance?

[y=.15cm, x=0.04* font=] (0,0) – coordinate (x axis mid) (20,0);

in 0 (,0pt) – (,15pt) node[anchor=south] ;

in 1,...,9 (,0pt) – (,5pt) node[anchor=south] ;

in 10 (,0pt) – (,15pt) node[anchor=south] ;

in 11,...,19 (,0pt) – (,5pt) node[anchor=south] ;

in 20 (,0pt) – (,15pt) node[anchor=south] ;

Very Low Very High

Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?

[y=.15cm, x=0.04* font=] (0,0) – coordinate (x axis mid) (20,0);

in 0 (,0pt) – (,15pt) node[anchor=south] ;

in 1,...,9 (,0pt) – (,5pt) node[anchor=south] ;

in 10 (,0pt) – (,15pt) node[anchor=south] ;

in 11,...,19 (,0pt) – (,5pt) node[anchor=south] ;

in 20 (,0pt) – (,15pt) node[anchor=south] ;

Very Low Very High

B.6.1 Participants Response

Would you please explain your reasons or feedback if you believe the suggested task does not make sense? Is the proposed user task, in your view, logical? If so, please elaborate.

1. It was a great task to see how people perform under pressure.
2. Yes, Of course, it is logical. The best thing is seeing and knowing your competitors and still keeping on with your work. Yeah. I found this task a great one to be part of.
3. How comfortable the user is with a computer is another variable not taken into account.
4. Task was good and it challenged my stress handling capability.
5. I didn’t understand the task until 1 minute in. Then after I understood.

6. Yes, it is fairly logical as the time limit often pushes people to another extent of stress. Also, the time limit also compels the user to complete the task as per Parkinsons law.

7. I think it made sense. I would have loved to have more information on the rules before I started, with that, I may have done better. But it was a good task. Enjoyed it and looks like a fun hangout game:)

8. I think the options used here to rate are not correct, instead of agree or disagree. It should be in relation to the question.

9. It makes some sense, but I can't say this can check stress levels up to that mark exactly.

10. It is logical what we have to do.

11. The task makes sense and is logical. Its ordering the numbers sequentially, you don't get more logical than that.

12. I like the task. Unfortunately, some on the numbers were missing in the spreadsheet. Due to this, I spent a long time being idle. Overall, its good.

13. It made sense but the rules were not all explained so it affected my performance.

14. This is logical under realtime circumstances to some extent I believe.

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